

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 1962

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MONOCOQUE CYLINDERS WITH CUTOUTS
VII - EXPERIMENTAL INVESTIGATION OF CYLINDERS
HAVING EITHER LONG BOTTOM CUTOUTS OR
SERIES OF SIDE CUTOUTS

By N. J. Hoff, Bruno A. Boley, and Joseph J. Mele

Polytechnic Institute of Brooklyn



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SUMMARY

Eight 24S-T¹ Alclad cylinders 20 inches in diameter and 0.012 inch in sheet thickness were tested in pure bending. They were between 57.87 and 77.16 inches long and were reinforced with 16 stringers and from 14 to 29 rings of various cross-sectional areas and spacings. Of these, five had a 45° cutout on the compression side extending over 33.44, 34.72, or 51.44 inches in the axial direction. The remaining three had a series of five 45° cutouts on each side.

All but one cylinder failed in general instability. The one that did not show the general-instability pattern failed in tension.

INTRODUCTION

The effect of cutouts on the stress distribution in and on the general-instability buckling load of monocoque cylinders has been discussed in references 1 to 6. These reports describe theoretical and experimental investigations which were carried out at the Polytechnic Institute of Brooklyn Aeronautical Laboratories. All the cylinders studied were loaded in pure bending. The cutout was located either on the compression side (symmetric cutout) symmetrically with respect to the most highly compressed stringer, or on a side (side cutout) in the neighborhood of the neutral axis.

Two main effects of the cutouts were studied. The first is the stress concentration which arises because of the discontinuities introduced by the cut members of the cylinder. The second is the decrease in the general-instability buckling load of the cylinders because of the increased freedom of motion of the cut members in the neighborhood of the cutout.

¹New designations: Alclad 24S-T sheet, now Alclad 24S-T3; 24S-T extrusions, now 24S-T4; Al7S-T rivets, now Al7S-T4.

All the cylinders previously tested, however, had cutouts of the same length except for three side-cutout specimens. Little information was obtained with regard to the effect of the length of the cutout upon the stress concentration. Furthermore, in all specimens tested, the axial length of the general-instability bulge was either longer than or equal to the length of the cutout. It was conjectured that with longer cutouts the bulge might be shorter than the cutout, and in some cases several waves might even develop.

Therefore it was felt that cylinders with varying lengths of cutout should be tested so as to supply the missing information. It is the purpose of the present report to describe tests which were run on cylinders with long cutouts. As long side cutouts are seldom met in practice, it was thought more advisable to construct cylinders with series of side cutouts. Thus the windows in the fuselage of a transport airplane were simulated.

The investigation described in this report was carried out at PIBAL under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. Acknowledgment is due to Mr. Sebastian V. Nardo who took part in the initial stages of the experimental work.

TEST SPECIMENS, RIG, AND PROCEDURE

Five cylinders with bottom cutouts and three with symmetrical side cutouts were tested. They were numbered consecutively from 72 to 79. Their characteristics are given in table I and shown in figure 1.

In all specimens the diameter was 20 inches, the sheet was 0.012 inch in thickness, and the longitudinal reinforcement consisted of sixteen 3/8-inch-square 24S-T aluminum-alloy stringers equally spaced along the circumference on the inside of the sheet. The number of rings varied between 14 and 22 and the lengths of the cylinders between 57.9 and 61.78 inches except for cylinder 77 which had 29 rings and was 77.10 inches long. The rings were either square or rectangular in cross section and were equally spaced on the outside of the sheet. The ring spacing was either 2.57 or 3.86 inches.

Rings and stringers were attached to the sheet covering by means of 1/8-inch Al7S-T aluminum-alloy round-head rivets. The rivet spacing was 0.643 inch on the stringers and approximately 1 inch on the rings. The rings and stringers were fastened to each other at their intersections by 1/8-inch steel machine screws except in cylinders 75 and 77 where 3/16-inch steel machine screws were used. Cylinder 77 had heat-treated Allen head bolts at the ring-stringer intersections in the vicinity of the cutout.

The test rig and the attachment of the cylinder to it were very much the same as those used in the tests described in reference 1. Differences worth mentioning are a heavy stiffening grid of steel channels added to the end stand and a lever arrangement operated by a mechanical jack which permitted the application of higher loads than the previous interlinked frame system. In addition a calibrated load link was inserted between the loading head and the cable supporting the counterweight for it. Throughout the test, the tension in the cable was kept constant by adding or removing weights from the counterweight pan. At each increase in the jack load the tension in the counterweight cable was checked.

The load was measured by means of pairs of Baldwin Southwark SR-4 type A-1 electric strain gages cemented to opposite sides of a calibrated load link. Either type A-1 or A-11 SR-4 electric strain gages were used to measure the strain in the stringers.

Each cylinder had three bands of gages with the exception of cylinder 77 which had four bands. A band is a series of gages arranged in a cross section of the cylinder around the entire circumference. In all specimens the second field from the loading head and a field in the center of the specimen had gages on every stringer. On the second field from the fixed end, gages were placed on every other stringer. With cylinder 77 the fourth band of gages was placed at 25 percent of the length of the specimen from the loading end. The position of the strain gages is shown in figure 1. The error in the strain-gage readings is believed to be less than a strain of $\pm 10 \times 10^{-6}$.

From five to seven load increments of approximately 500 to 1000 pounds were applied to each test specimen. At each stage of loading, readings of all gages were taken and then checked by a second observer. This loading procedure was continued up to the buckling load, which was characterized by a sudden drop of the applied moment and a corresponding jump in the distorted shape. An exception to this type of failure was found with cylinder 74, in which a gradual rather than a sudden decrease of the applied load was encountered.

PRESENTATION OF TEST RESULTS

Results of the strain measurements in the stringers are presented for one end band near each end and for one band in the middle of each specimen. In the case of cylinder 77, measurements made in an additional intermediate band are also shown. The presentation is in the form of diagrams in which the strain is plotted against the distance of the stringer from the horizontal diameter of the cylinder. These basic data are contained in figures 2 to 26.

The variation of the strain along the stringer at the edge of the cutout of cylinder 77 is shown in figure 27 for various loads. The length of the cutout in this cylinder was approximately 2.6 times the diameter of the cylinder, or approximately 50 percent greater than that of the cutouts of cylinders 72, 73, 74, and 75.

A comparison of the strains in the middle bands of cylinders 75 and 77 is given for two applied loads in figures 28 and 29. These cylinders were identical except that their cutouts were approximately 1.56 and 2.6 times their diameter, respectively.

The maximum moment and strain attained by each cylinder are listed in table II, together with a comment on the type of failure. The behavior after collapse is described in table III.

Photographs of the test specimens after failure are presented in figures 30 to 38.

DISCUSSION OF TEST RESULTS

Strain Distribution

At low loads for cylinders with bottom cutouts good straight lines were obtained in the plots of strain against distance from the horizontal diameter except near the edge of the cutout. Near the edge stringer the strain always decreases in the full bands, increases in the middle bands of cylinders 74 and 75, and decreases in the middle bands of cylinders 72 and 73.

In general, for side cutouts the linearity is not so good as for bottom cutouts especially on the compression side. However, the deviations from linearity appear to be small.

As a rule, good agreement was obtained between measurements taken on locations symmetrically situated with respect to the vertical planes of symmetry of the cylinders. Exceptions are band H of cylinder 76 and bands B and V of cylinder 74. Moreover, considerable deviations from symmetry occurred at high loads when random displacements were induced by the approach of buckling.

In the edge stringer of cylinder 77 the strains in the middle band were considerably higher than in the full portions of the cylinder. The strain in the cutout region is highest at about the 25-percent mark along the cutout and is lower in the center. Close to failure, however, the pattern changes entirely since the edge stringer takes less than its share while the stringers farther away from the cutout take more. This is true for cylinder 77, the specimen with the longest cutout, but not necessarily for all the others.

Cylinders 75 and 77 were identical except that the lengths of their cutouts were 1.56 and 2.6 times their diameter, respectively. The strain distribution for these two specimens was almost the same except very close to the cutout. For example, at low loads the edge stringer was more highly stressed with the short cutout than with the long cutout.

At high loads, usually above 75 percent of the critical moment, the variations from linearity are considerable for all cylinders. This is because the strain readings reflect random variations in the displacements at loads close to failure.

Failure of Cylinders with Bottom Cutouts

The five cylinders which had bottom cutouts were cylinders 72, 73, 74, 75, and 77. Of these, the first three failed in a definite general-instability pattern. In cylinder 75 failure occurred first by the shearing of two bolts at ring-stringer intersections. The load was then completely removed and the bolts replaced. When the load was reapplied, the specimen failed at a higher moment by the shearing of one of the new bolts and the cracking of an edge stringer at the bolt failure. In cylinder 77, which had the longest cutout, buckling was precipitated by a tension diagonal failure of one of the sheet panels adjacent to the cutout. Except in one side of cylinder 75 where the bolt failure renders the results doubtful, all the buckling shapes of the edge stringers resembled that of a fixed-ended column. The length of the distortion of the edge stringer was slightly longer than the cutout in cylinder 72, slightly shorter than the length of the cutout for cylinders 73, 74, and 75, and about two-thirds the length of the cutout for cylinder 77. The side of cylinder 75 on which the bolts failed was the only edge stringer to fail in an S-shaped curve.

Failure of Cylinders with Side Cutouts

Three cylinders with side cutouts were tested. Two of these, cylinders 76 and 79, failed in a general-instability pattern and the third, cylinder 78, failed in tension.

Of the three specimens, the one that failed in tension required the highest moment, namely, 451,225 inch-pounds. Several stringers on the upper side of the cylinder tore close to the loading head.

Cylinders 76 and 79 failed at 324,000 and 370,000 inch-pounds, respectively. Both buckled in a general-instability pattern in which the bottom stringer was S-shaped and the sides were pushed in where the bottom stringer buckled out.

CONCLUSIONS

Pure bending tests carried out with eight reinforced monocoque cylinders substantiated the conjecture that the wave length of the general-instability bulge can be smaller than the length of the cutout. It was found that such a situation arises only when the cutout is considerably longer than most cutouts encountered in actual airplanes.

When two specimens were tested which differed only in the length of the cutout and the total length of the cylinder, the specimen having the longer cutout failed at a lower applied load.

Polytechnic Institute of Brooklyn
Brooklyn, N.Y., July 12, 1948

REFERENCES

1. Hoff, N. J., and Boley, Bruno A.: Stresses in and General Instability of Monocoque Cylinders with Cutouts. I - Experimental Investigation of Cylinders with a Symmetric Cutout Subjected to Pure Bending. NACA TN 1013, 1946.
2. Hoff, N. J., Boley, Bruno A., and Klein, Bertram: Stresses in and General Instability of Monocoque Cylinders with Cutouts. II - Calculation of the Stresses in a Cylinder with a Symmetric Cutout. NACA TN 1014, 1946.
3. Hoff, N. J., Boley, Bruno A., and Klein, Bertram: Stresses in and General Instability of Monocoque Cylinders with Cutouts. III - Calculation of the Buckling Load of Cylinders with Symmetric Cutout Subjected to Pure Bending. NACA TN 1263, 1947.
4. Hoff, N. J., Boley, Bruno A., and Viggiano, Louis R.: Stresses in and General Instability of Monocoque Cylinders with Cutouts. IV - Pure Bending Tests of Cylinders with Side Cutout. NACA TN 1264, 1948.
5. Hoff, N. J., and Klein, Bertram: Stresses in and General Instability of Monocoque Cylinders with Cutouts. V - Calculation of the Stresses in Cylinders with Side Cutout. NACA TN 1435, 1948.
6. Hoff, N. J., Klein, Bertram, and Boley, Bruno A.: Stresses in and General Instability of Monocoque Cylinders with Cutouts. VI - Calculation of the Buckling Load of Cylinders with Side Cutout Subjected to Pure Bending. NACA TN 1436, 1948.

TABLE I

DATA OF CYLINDERS

Cylinder	Number of stringers	Number of rings	Stringer size	Ring size	Sheet thickness (in.)	Radius of cylinder (in.)	Angle of cutout (deg)	Length of cylinder (in.)	Length of cutout (in.)	Percent length cutout	Ring spacing
72	16	14	3/8 x 3/8	1/8 x 1/2	0.012	10	45 (bottom)	57.9	34.74	60	3.86
73	16	14	3/8 x 3/8	1/4 x 1/2	.012	10	45 (bottom)	57.9	34.74	60	3.86
74	16	22	3/8 x 3/8	1/4 x 1/2	.012	10	45 (bottom)	59.11	33.41	56.5	2.57
75	16	22	3/8 x 3/8	3/8 x 3/8	.012	10	45 (bottom)	59.11	33.41	56.5	2.57
76	16	15	3/8 x 3/8	1/8 x 1/2	.012	10	2-45 (two sides)	61.78	47.72	-----	3.86
77	16	29	3/8 x 3/8	3/8 x 3/8	.012	10	45 (bottom)	77.10	51.40	66.7	2.57
78	16	22	3/8 x 3/8	1/4 x 1/2	.012	10	2-45 (two sides)	59.11	47.71	-----	2.57
79	16	22	3/8 x 3/8	1/8 x 1/2	.012	10	45 (two sides)	59.11	47.71	-----	2.57

^aLength of each of five symmetrical cutouts.

TABLE II
EXPERIMENTAL MAXIMUM STRAINS AND MOMENTS

Cylinder	Experimental maximum moment	Experimental maximum strain	Type of failure	Description of cylinder after buckling		Jack load
				Near side or stringer 8	Far side or stringer 11	
72	212,544	-29.72	General instability	Out $\frac{1}{2}$ sine, 9 fields	In $\frac{1}{2}$ sine, 9 fields	2952
73	272,664	-21.18	General instability	In $\frac{1}{2}$ sine, 8 fields	Out $\frac{1}{2}$ sine, 8 fields	3787
74	323,208	-21.29	General instability ¹	Out $\frac{1}{2}$ sine, 10 fields	Out $\frac{1}{2}$ sine, 13 fields	4489
75	309,600	-36.32	Local failure ²	Out $\frac{1}{2}$ sine, 9 fields	Out S-shape, 13 fields	5189
76	324,000	-20.35	General instability	Side cutout	Side cutout	4500
77	306,720	-28.50	General instability	Out $\frac{1}{2}$ sine, 11 fields	Out $\frac{1}{2}$ sine, 15 fields	4510
78	451,224	-32.71	Tension failure ³	Side cutout	Side cutout	6267
79	370,800	-23.58	General instability	Side cutout	Side cutout	5150

¹After a certain point the load gradually decreased (568 lb). Skin began to rupture and there was no collapse of the structure.

²Bolt at intersection of stringer and ring sheared, which precipitated failure that resembled general type of instability.

³Stringers on tension side of cylinder failed in tension.

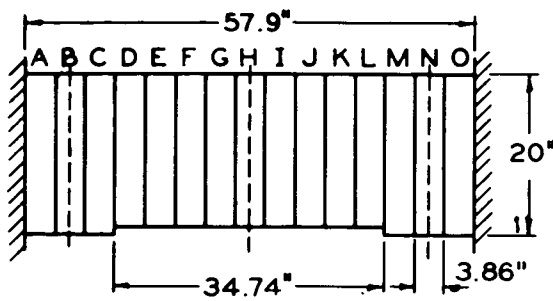


TABLE III
BEHAVIOR AFTER COLLAPSE

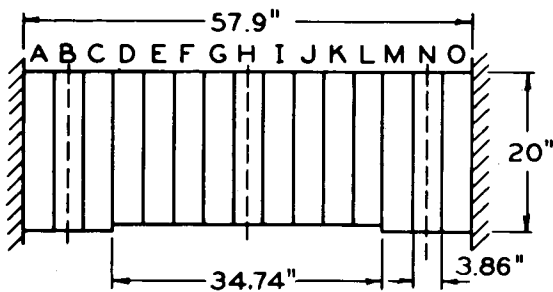
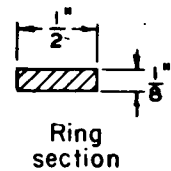
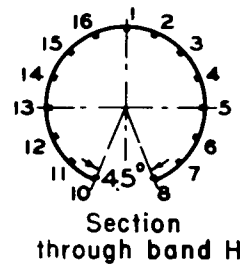
Cylinder	Failed at		After collapse		Second failure after overnight rest		After collapse	
	Load on jack	Moment	Load on jack	Moment	Load on jack	Moment	Load on jack	Moment
72	2952	212,544	2730	196,560	2800	201,600	2535	182,520
73	3787	272,664	3579	257,688	3996	257,712	3352	241,344
74	4489	323,208	3921	282,312	3571	257,112	3401	244,872
75	4300	309,600	3997	287,784	5189	373,608	5019	361,368
76	4500	324,000	2607	187,704	2916	209,952	2644	190,368
77	4260	306,720	3560	256,320	3693	265,896	3051	219,672
a78	6267	451,224						
79	5150	370,800	3404	173,088	2840	204,480	2462	177,264

^aCylinder 78 failed in tension.

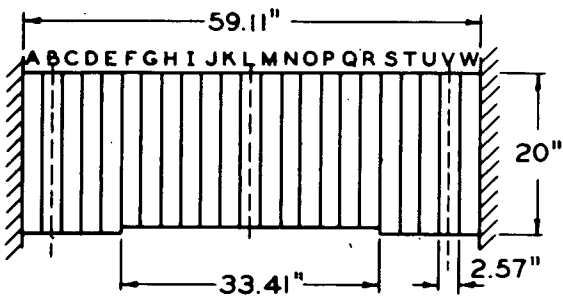
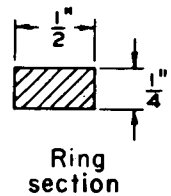
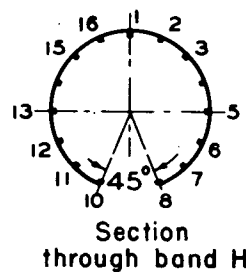




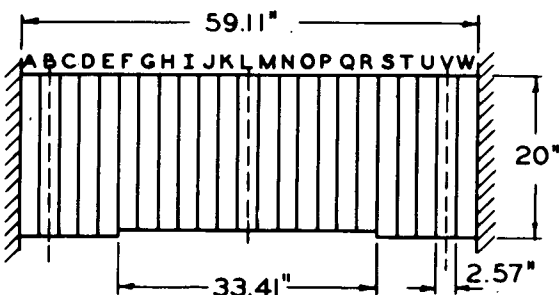
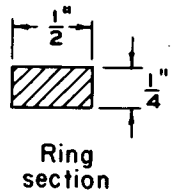
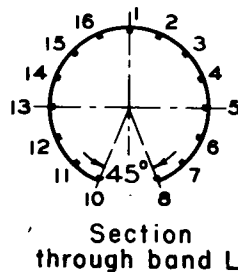
Cylinder 72



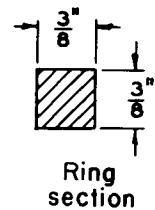
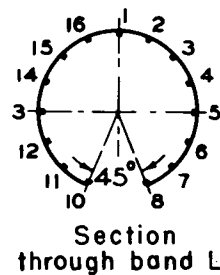
Cylinder 73



Cylinder 74



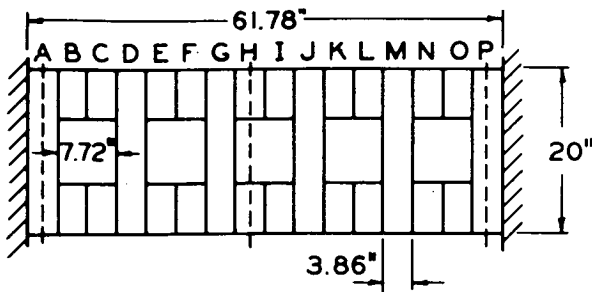
Cylinder 75



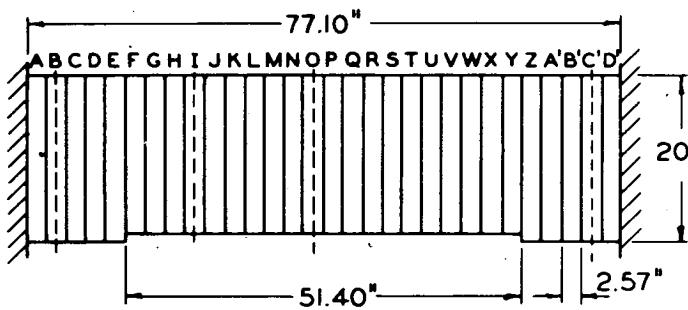
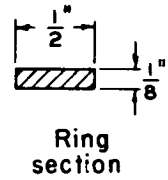
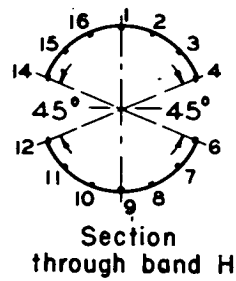
----- Position of strain gages

(a) Cylinders 72 to 75.

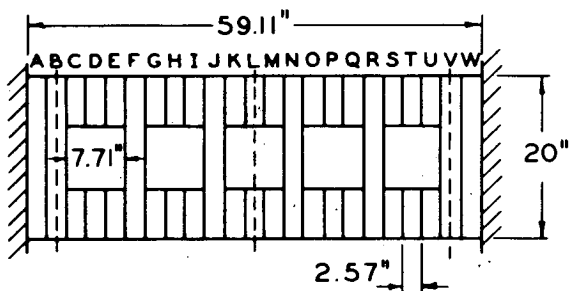
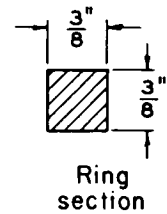
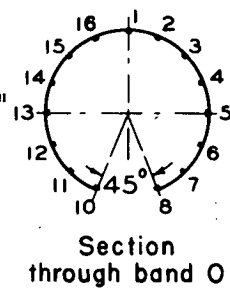
Figure 1.- Schematic drawings of test specimens.



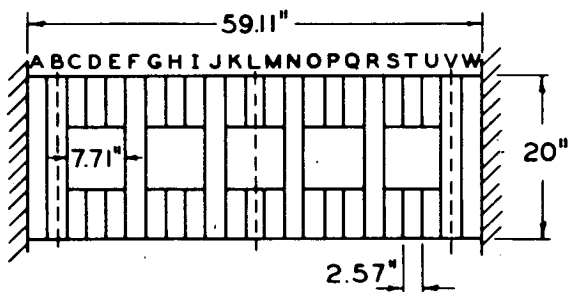
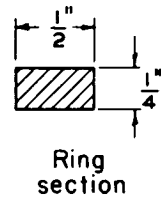
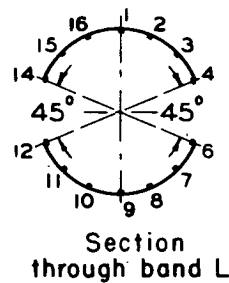
Cylinder 76



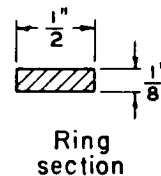
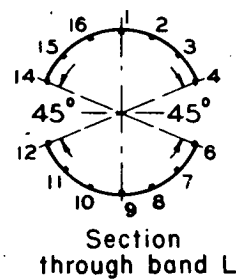
Cylinder 77



Cylinder 78



Cylinder 79



----- Position of strain gages

(b) Cylinders 76 to 79.

Figure 1.- Concluded.

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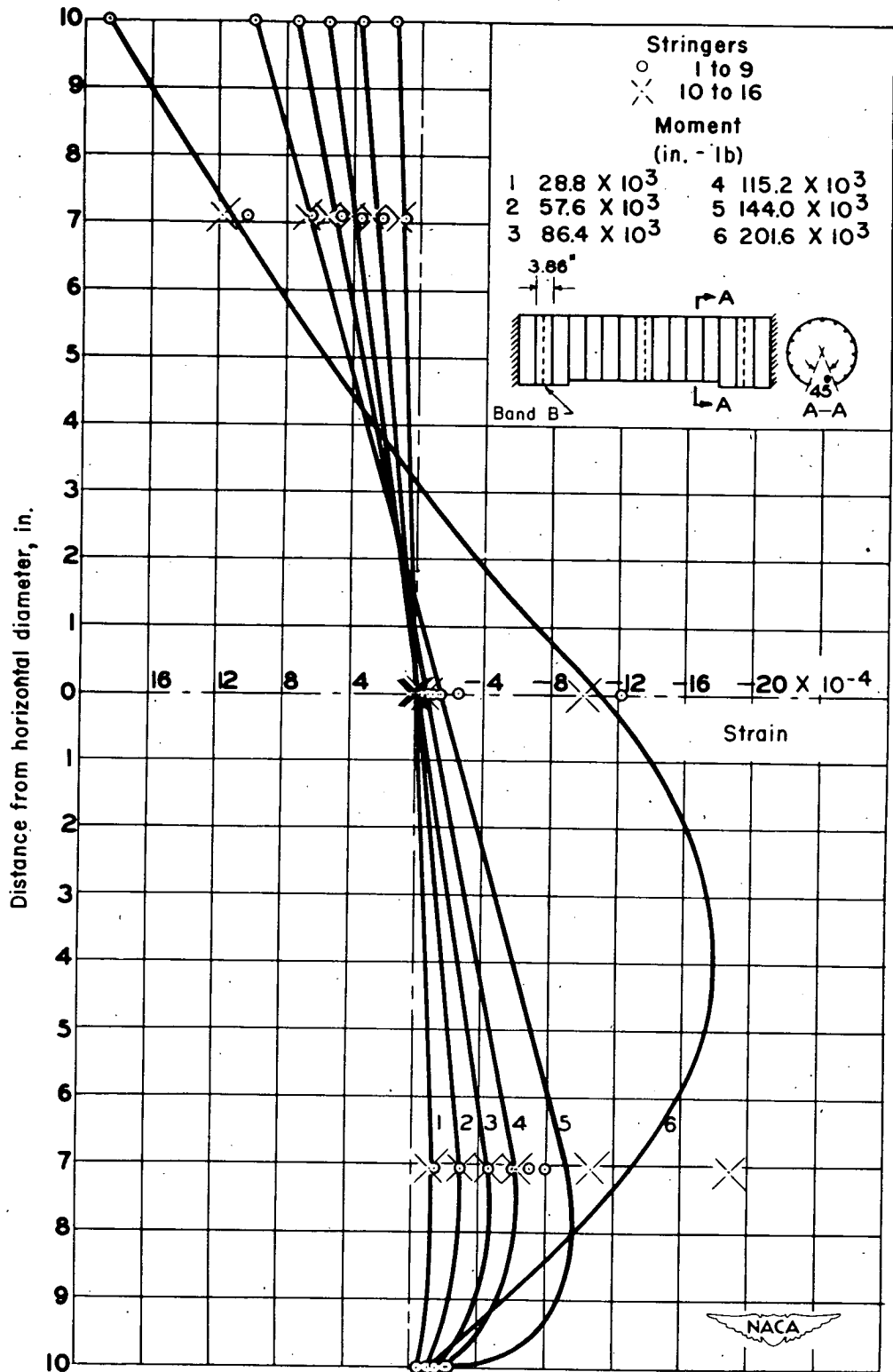


Figure 2.- Strain diagram of cylinder 72. Band B.

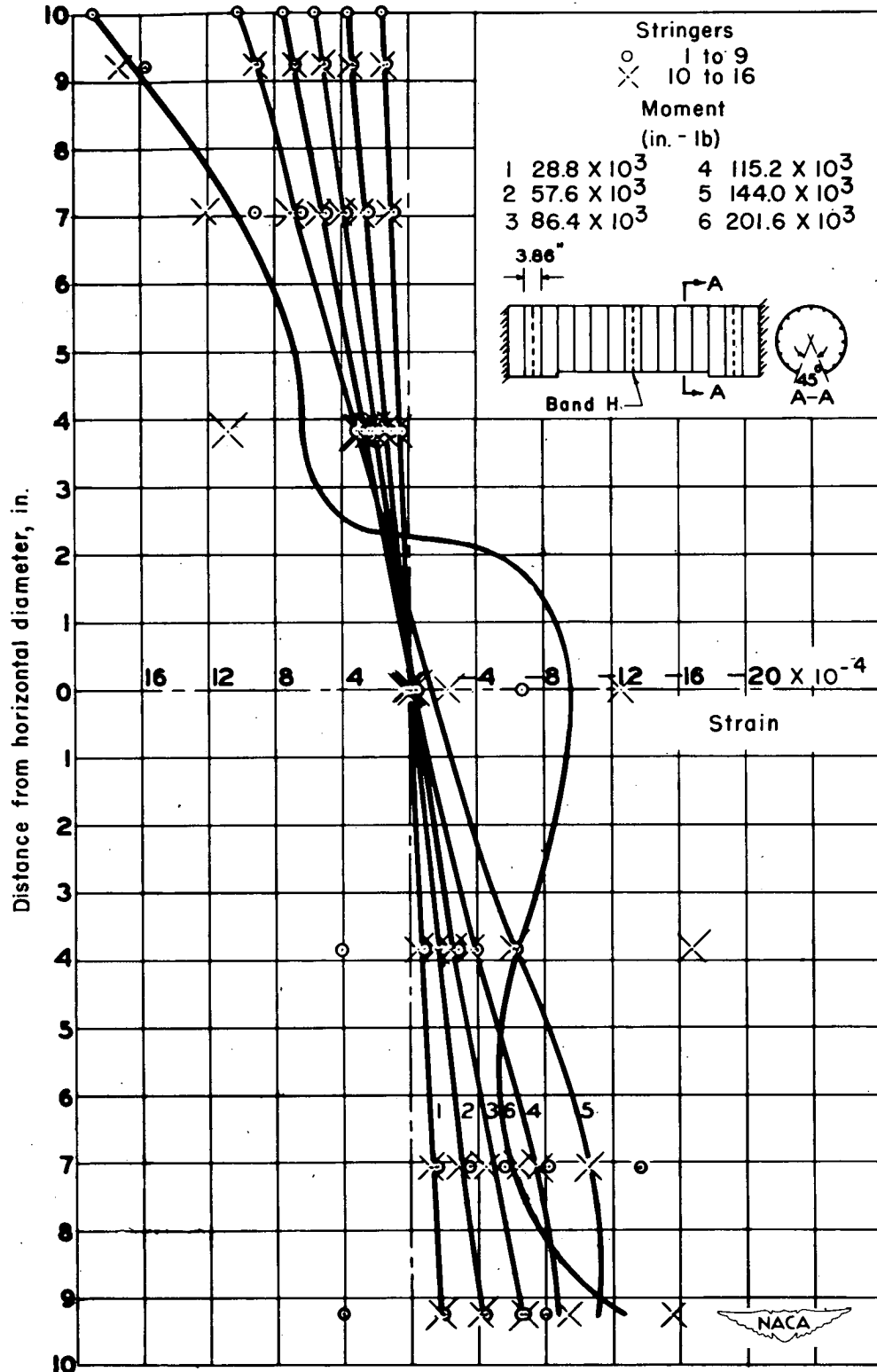


Figure 3.- Strain diagram of cylinder 72. Band H.

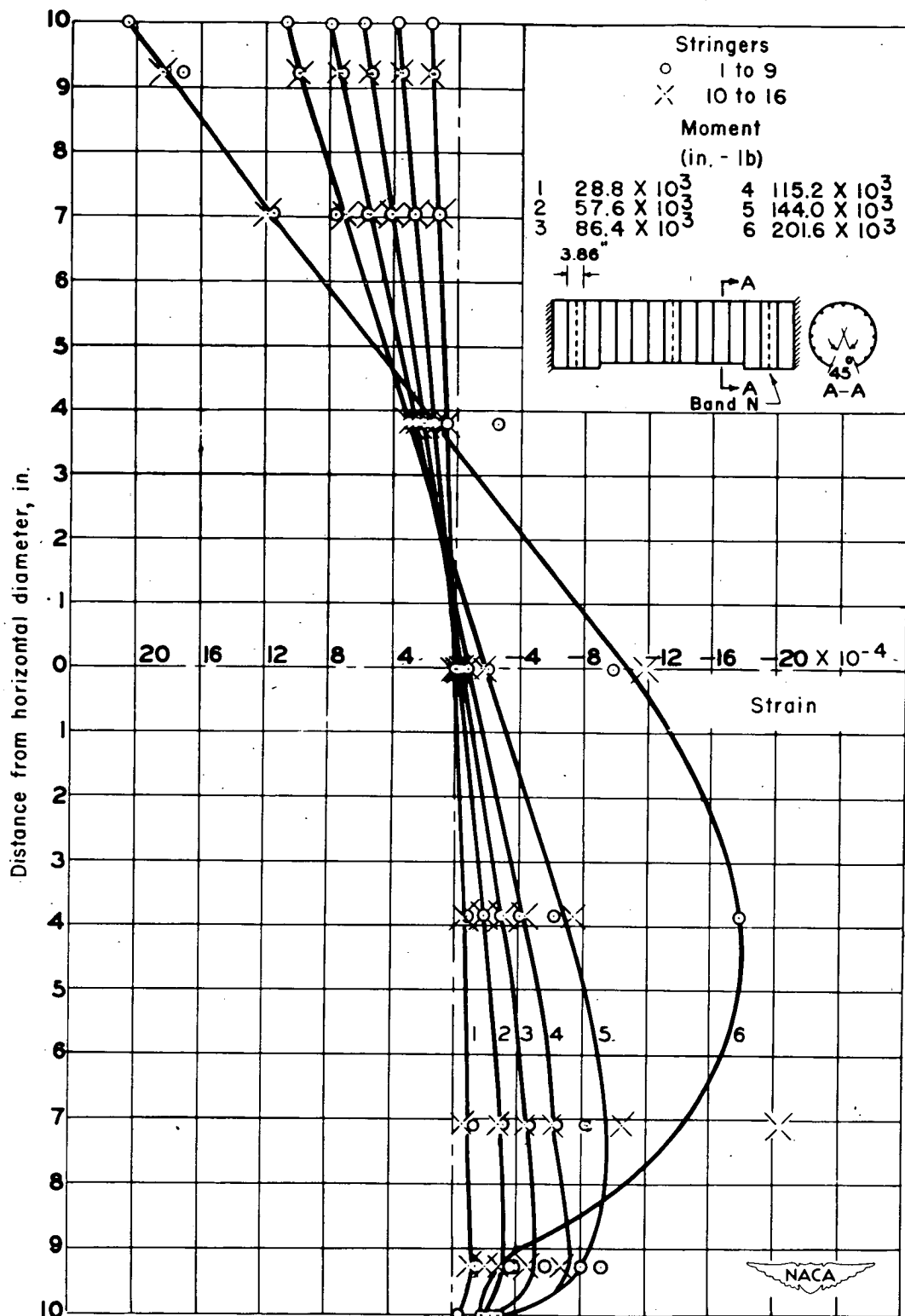


Figure 4.- Strain diagram of cylinder 72. Band N.

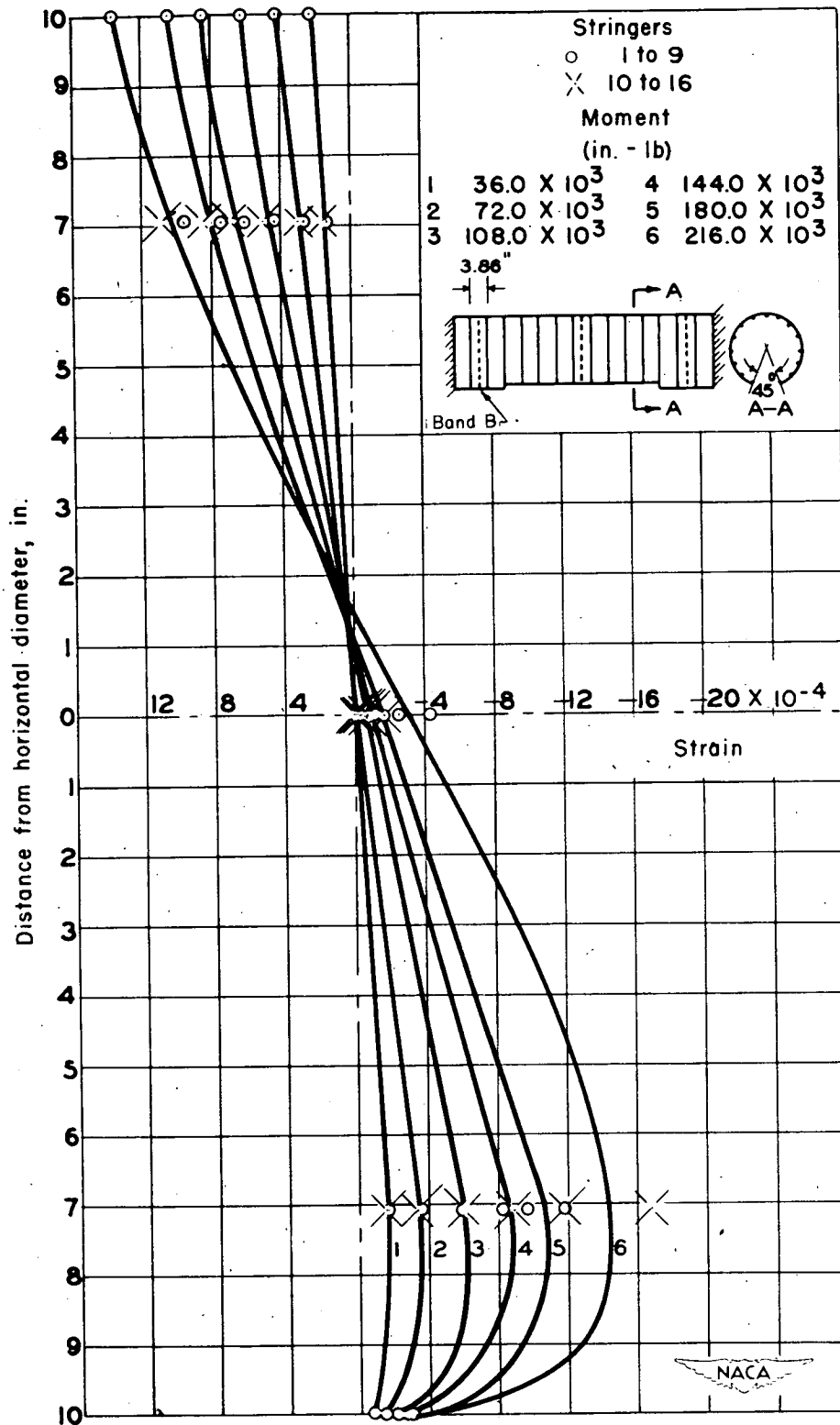


Figure 5.- Strain diagram of cylinder 73. Band B.

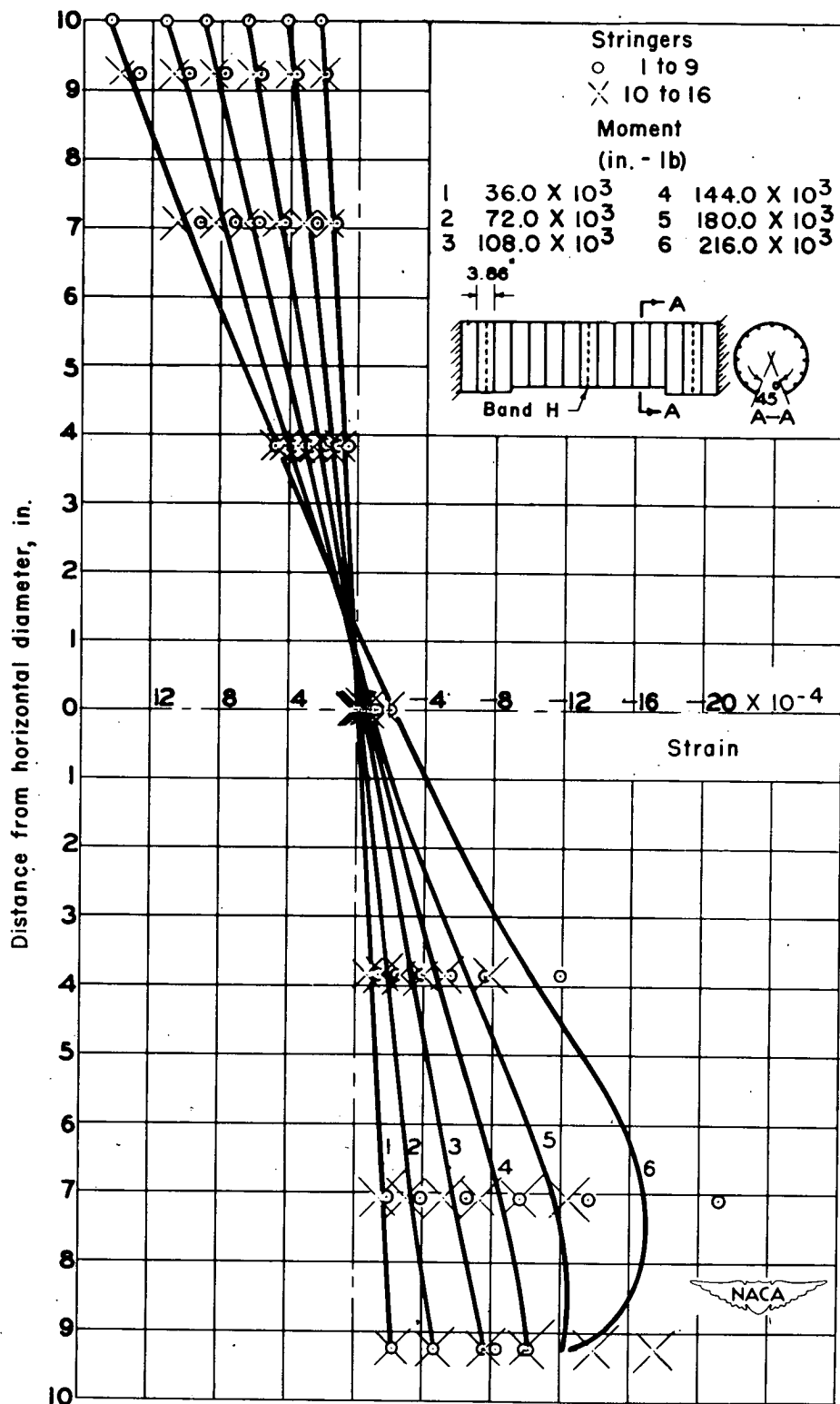


Figure 6.- Strain diagram of cylinder 73. Band H.

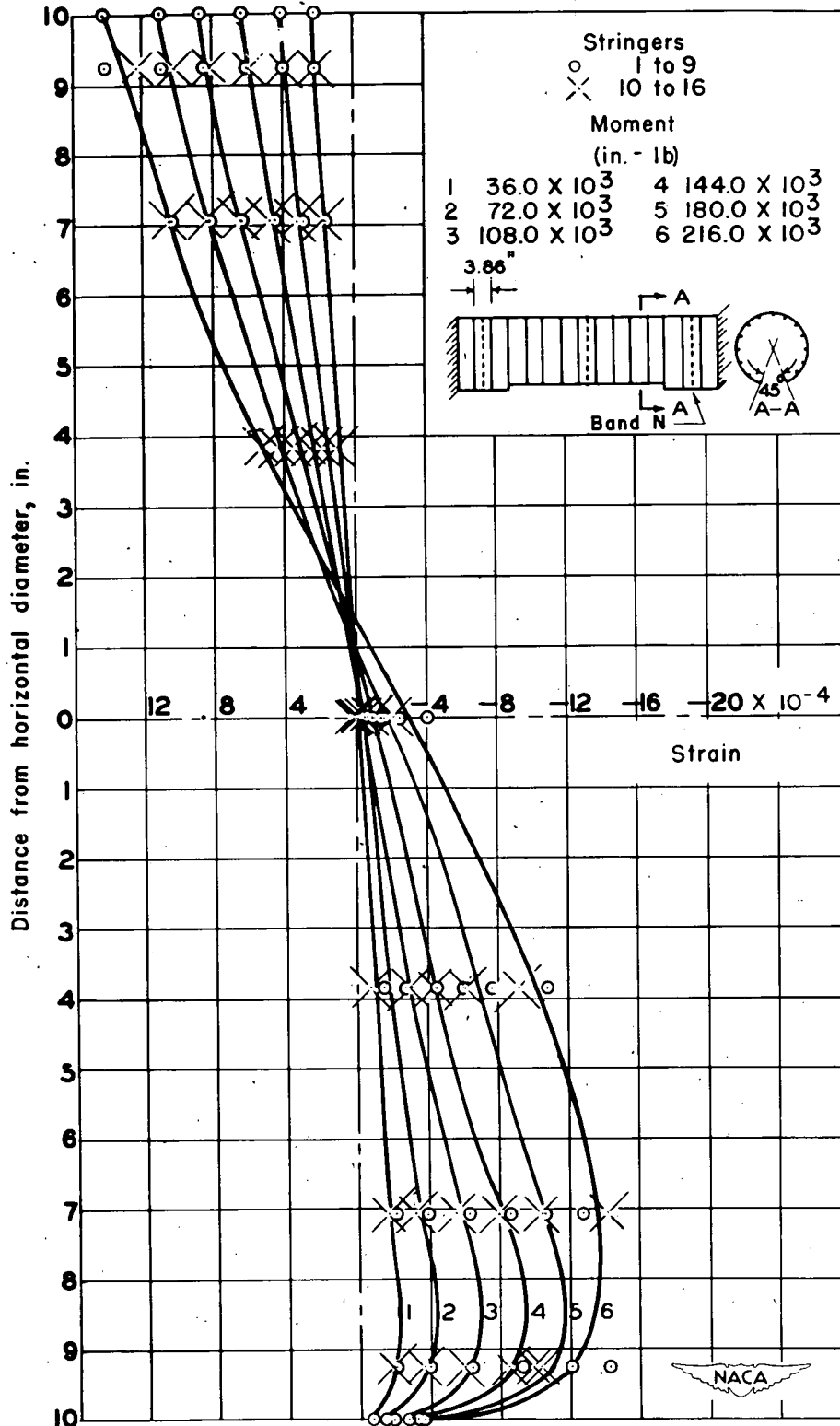


Figure 7.- Strain diagram of cylinder 73. Band N.

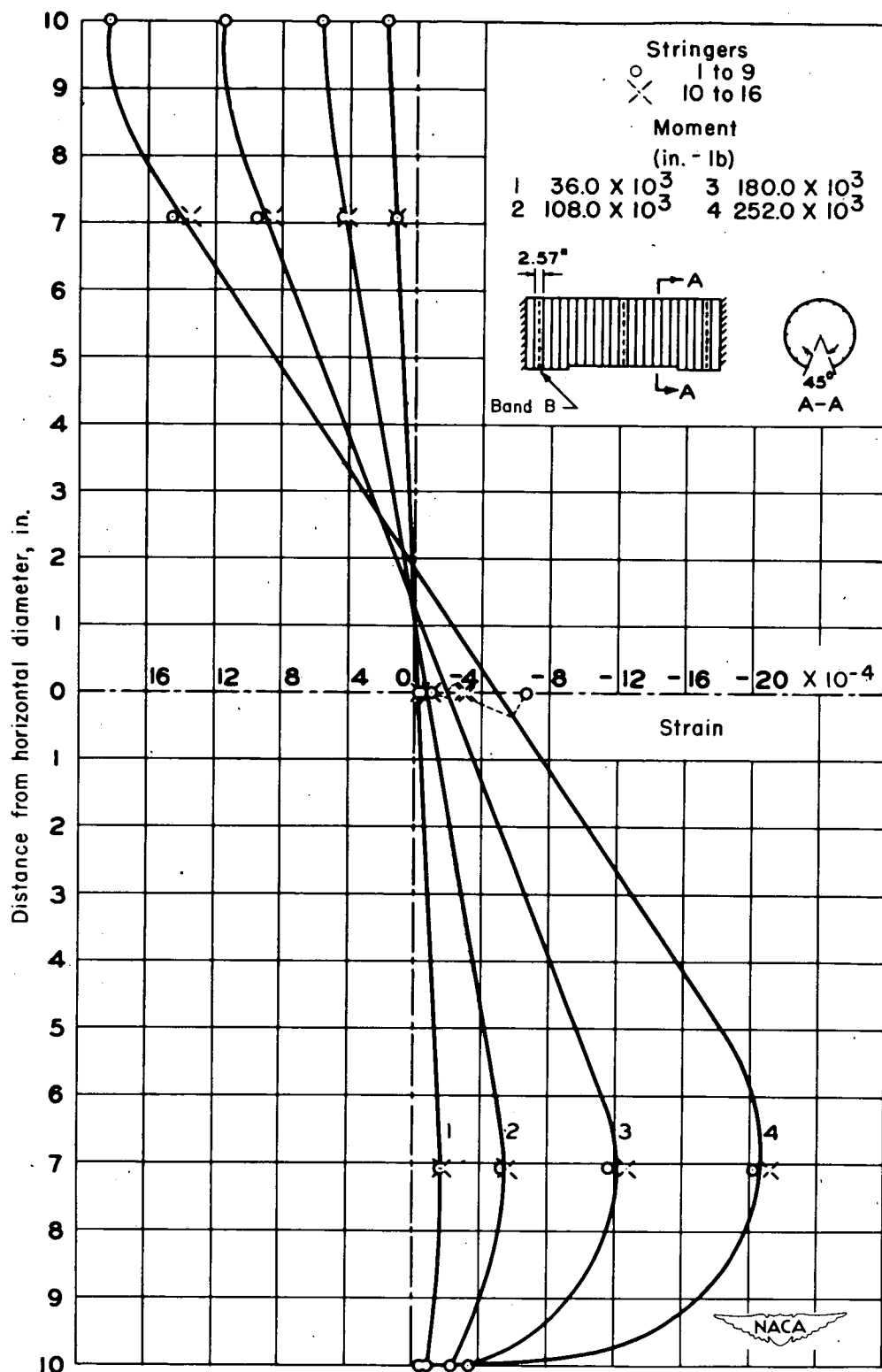


Figure 8.- Strain diagram of cylinder 74. Band B.

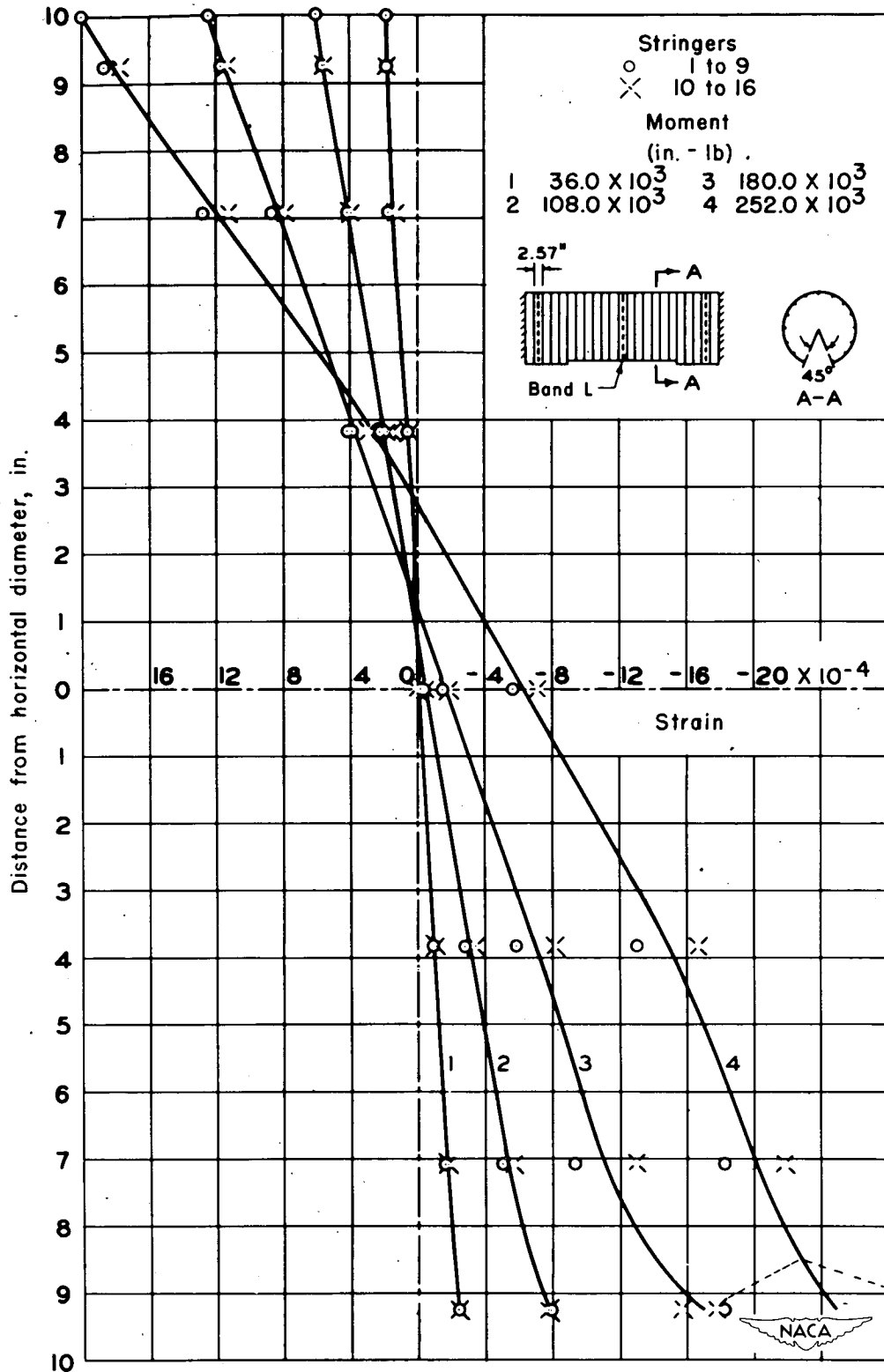


Figure 9.- Strain diagram of cylinder 74. Band L.

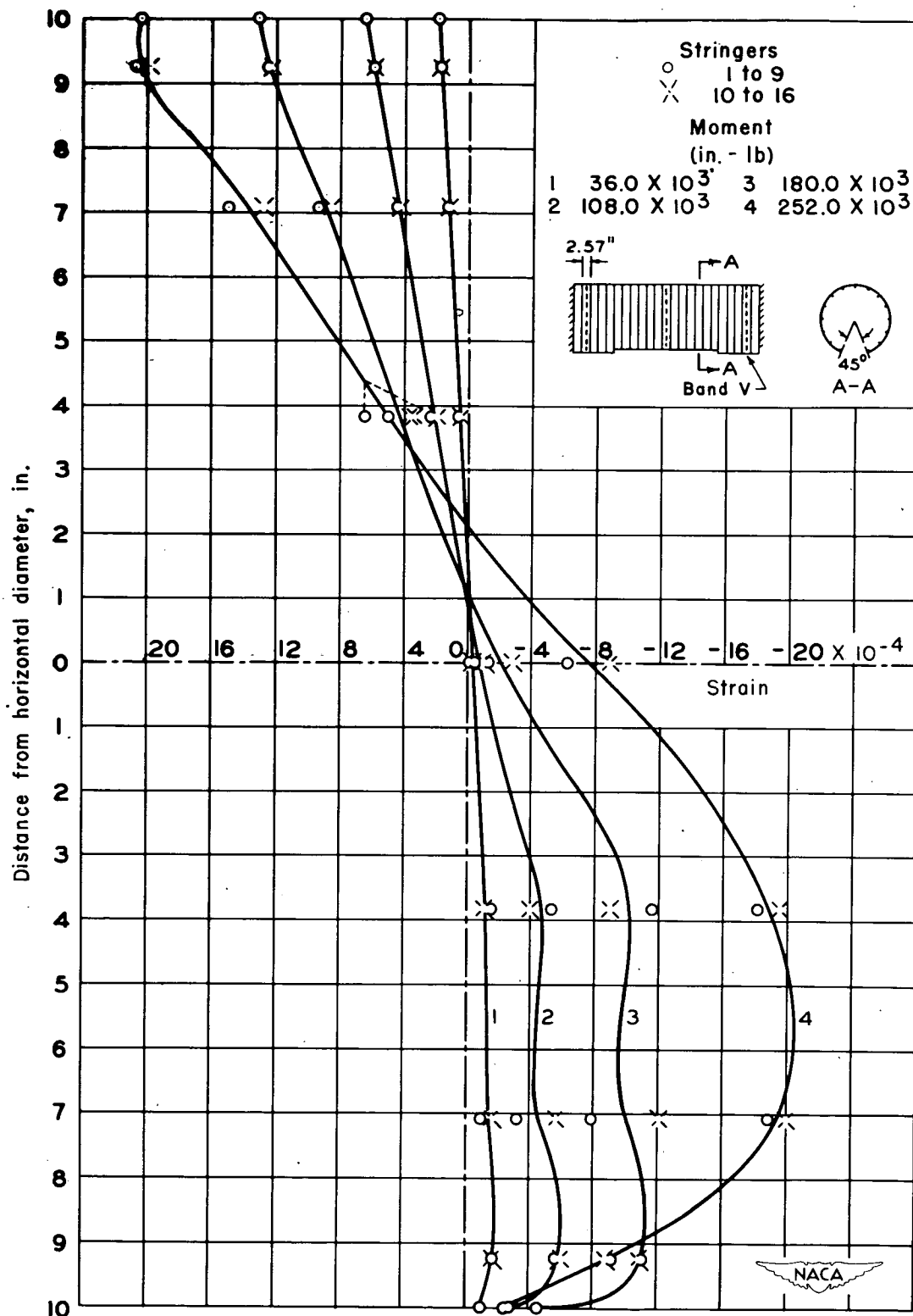


Figure 10.- Strain diagram of cylinder 74. Band V.

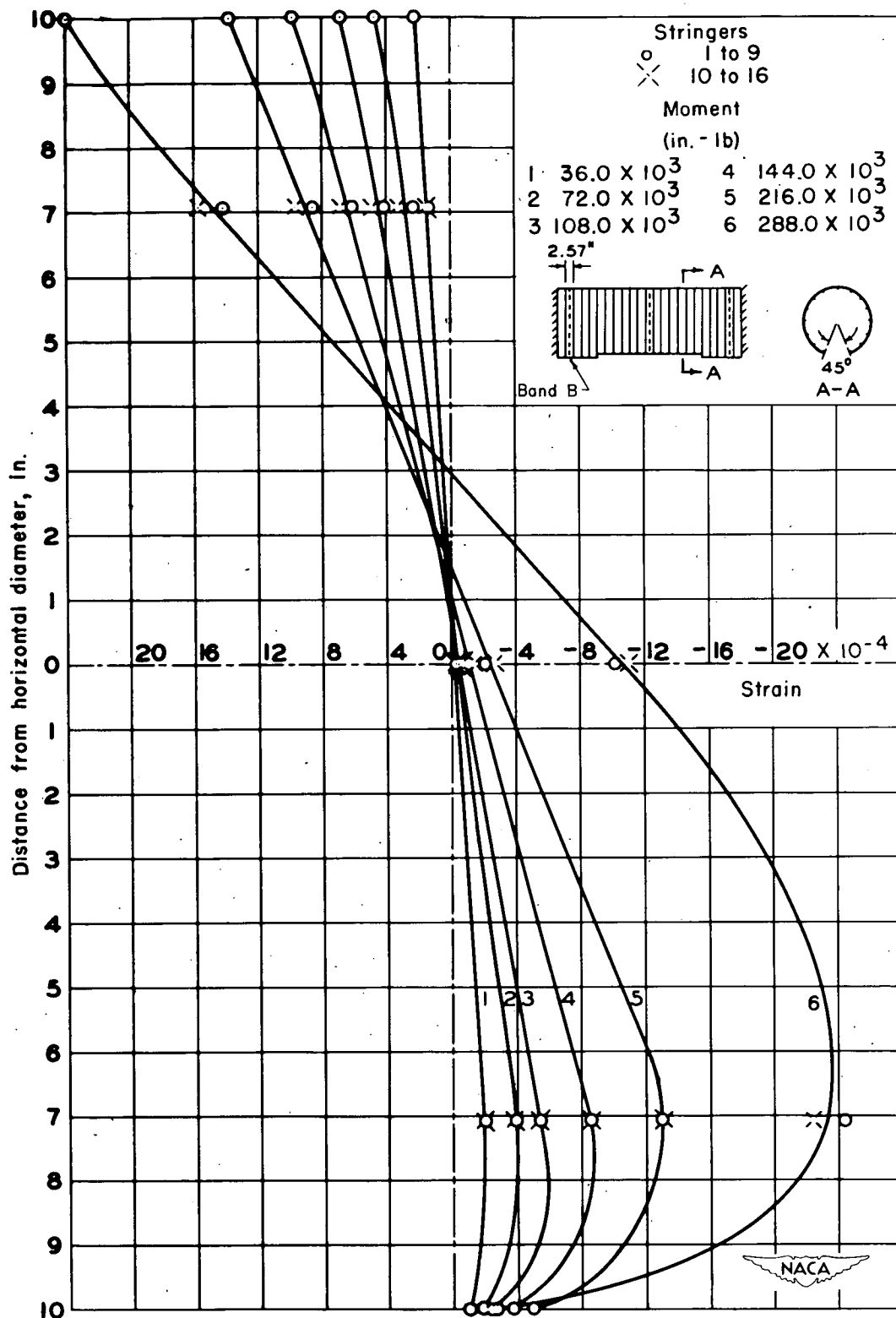


Figure 11.- Strain diagram of cylinder 75. Band B.

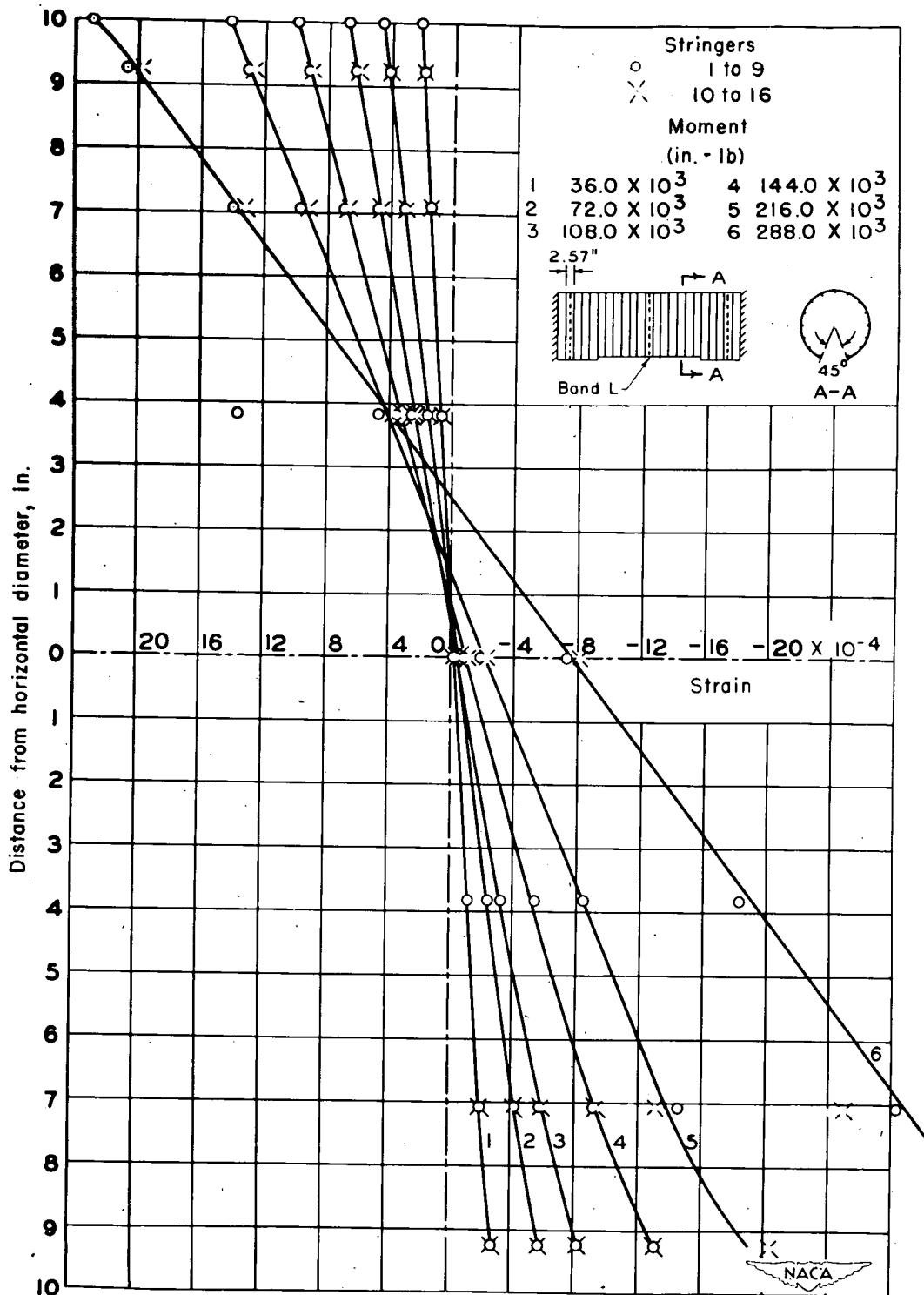


Figure 12.- Strain diagram of cylinder 75. Band L.

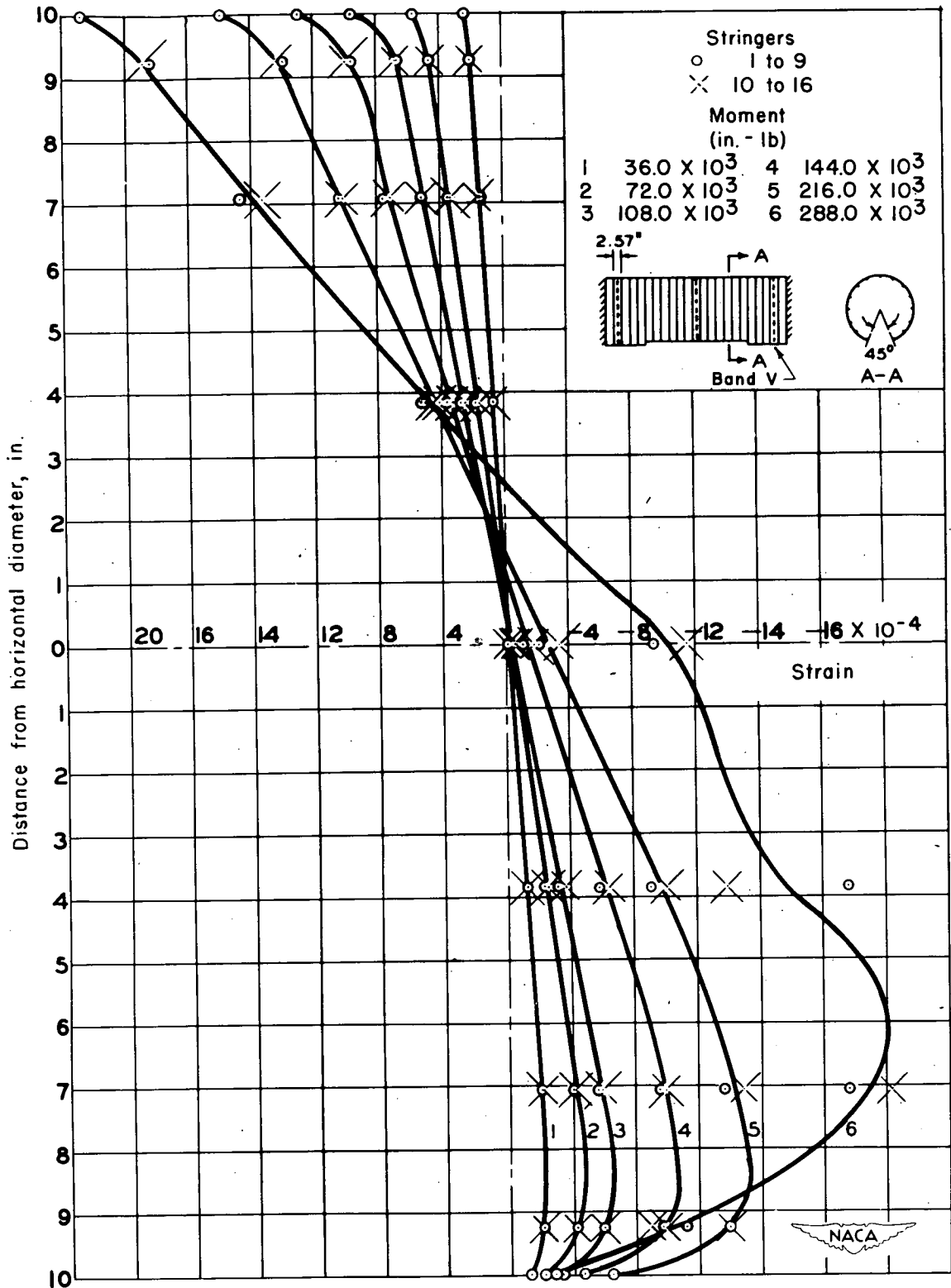


Figure 13.- Strain diagram of cylinder 75. Band V.

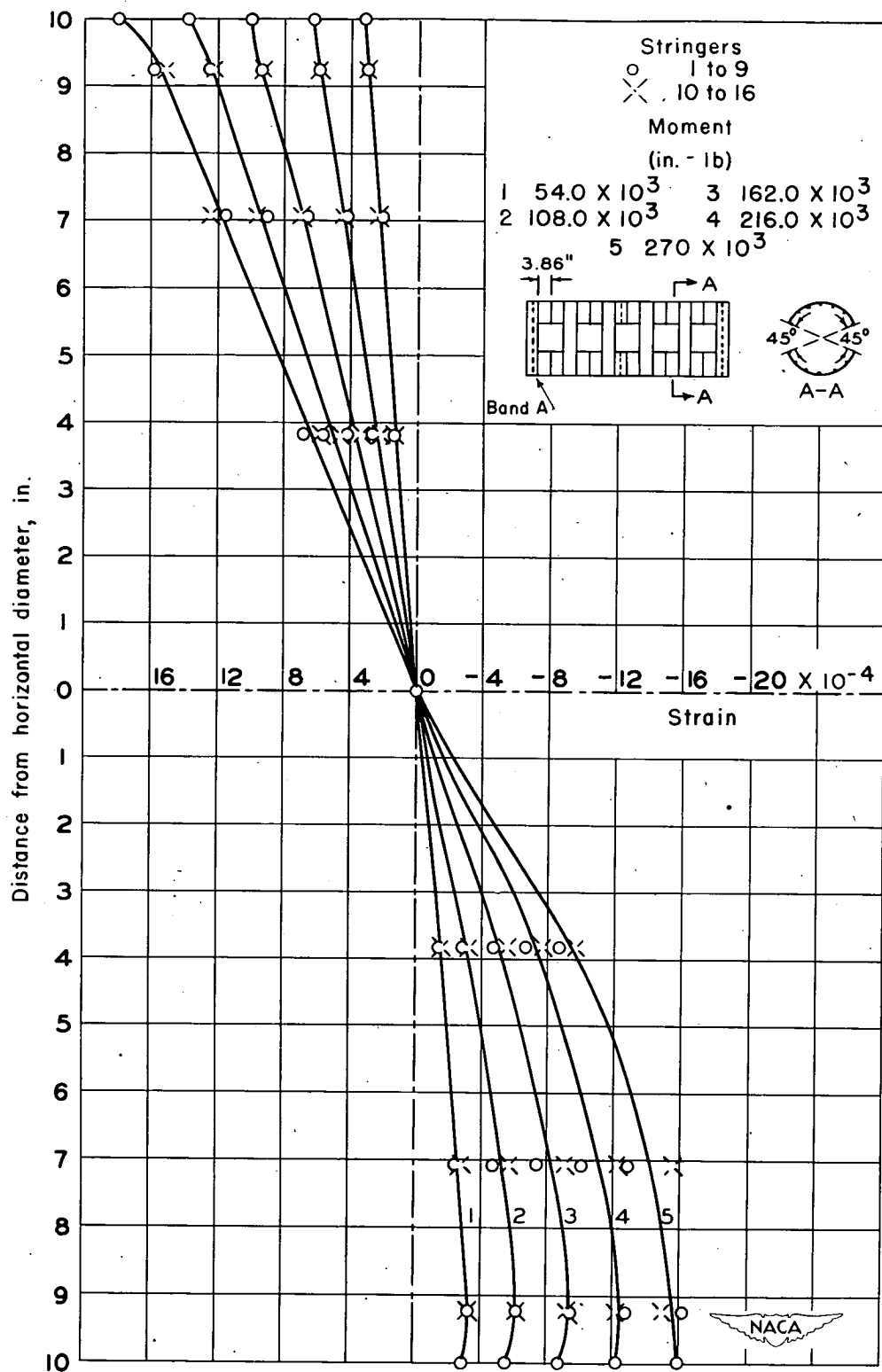


Figure 14.- Strain diagram of cylinder 76. Band A.

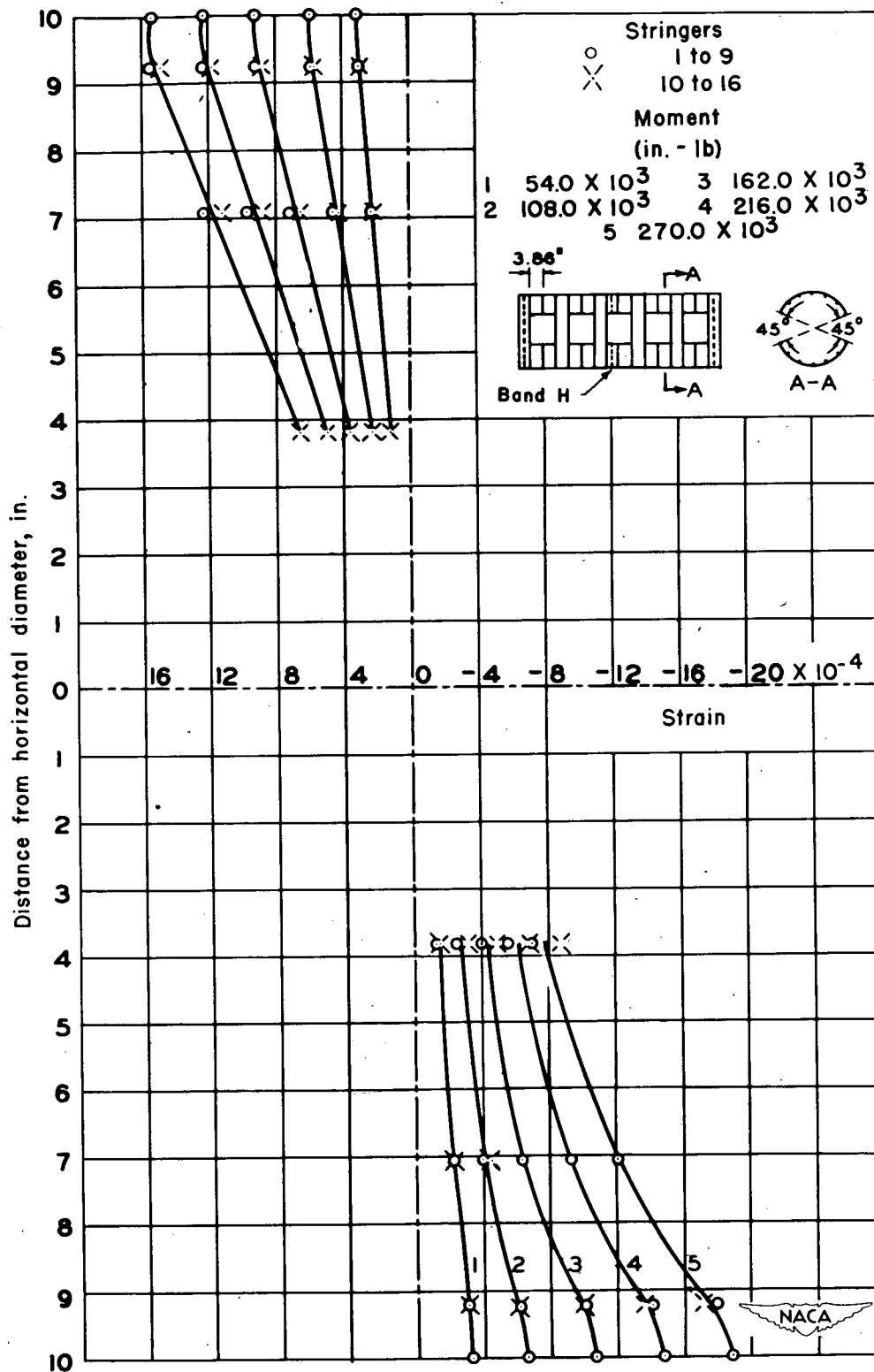


Figure 15.- Strain diagram of cylinder 76. Band H.

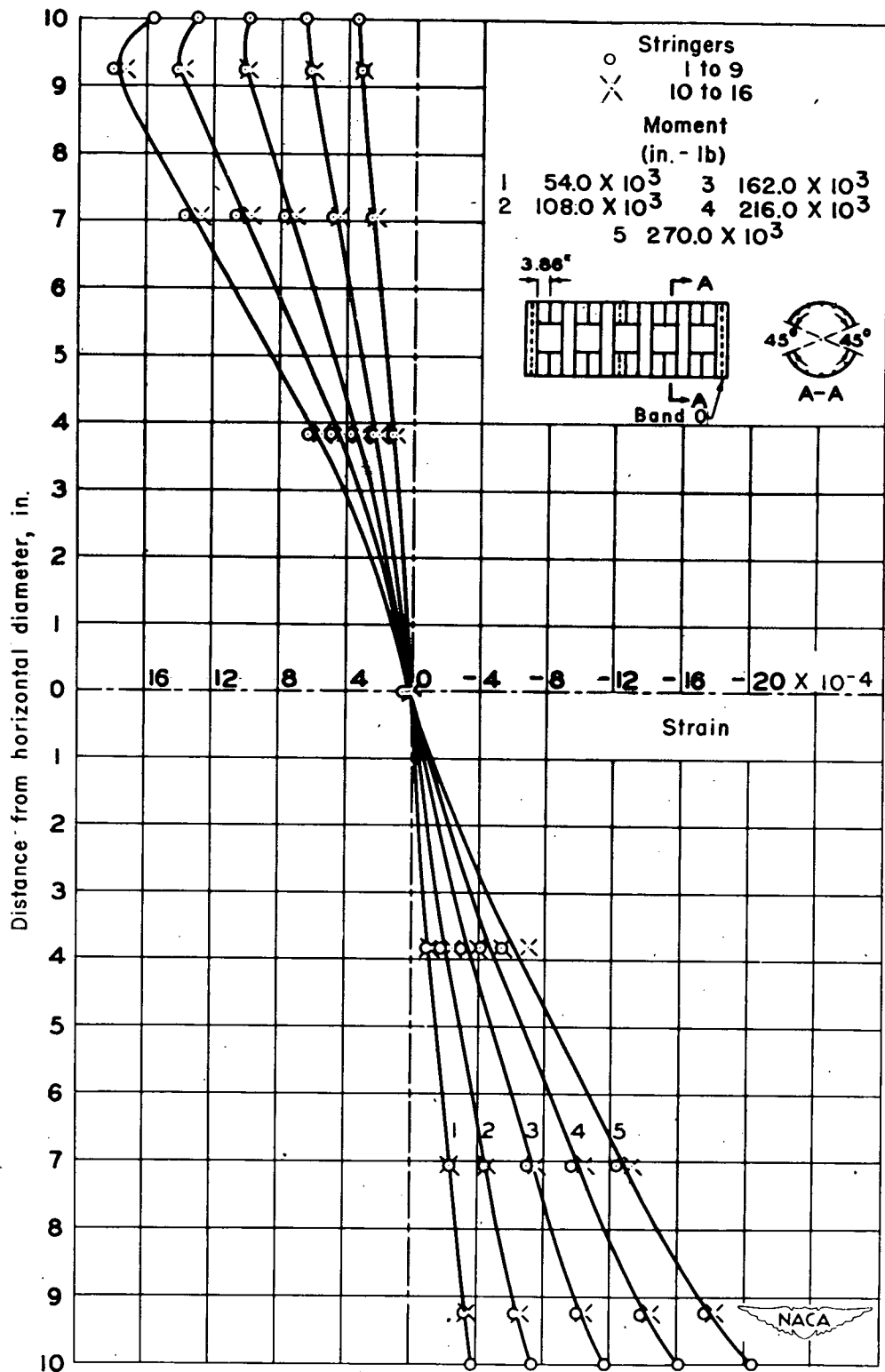


Figure 16.- Strain diagram of cylinder 76. Band O.

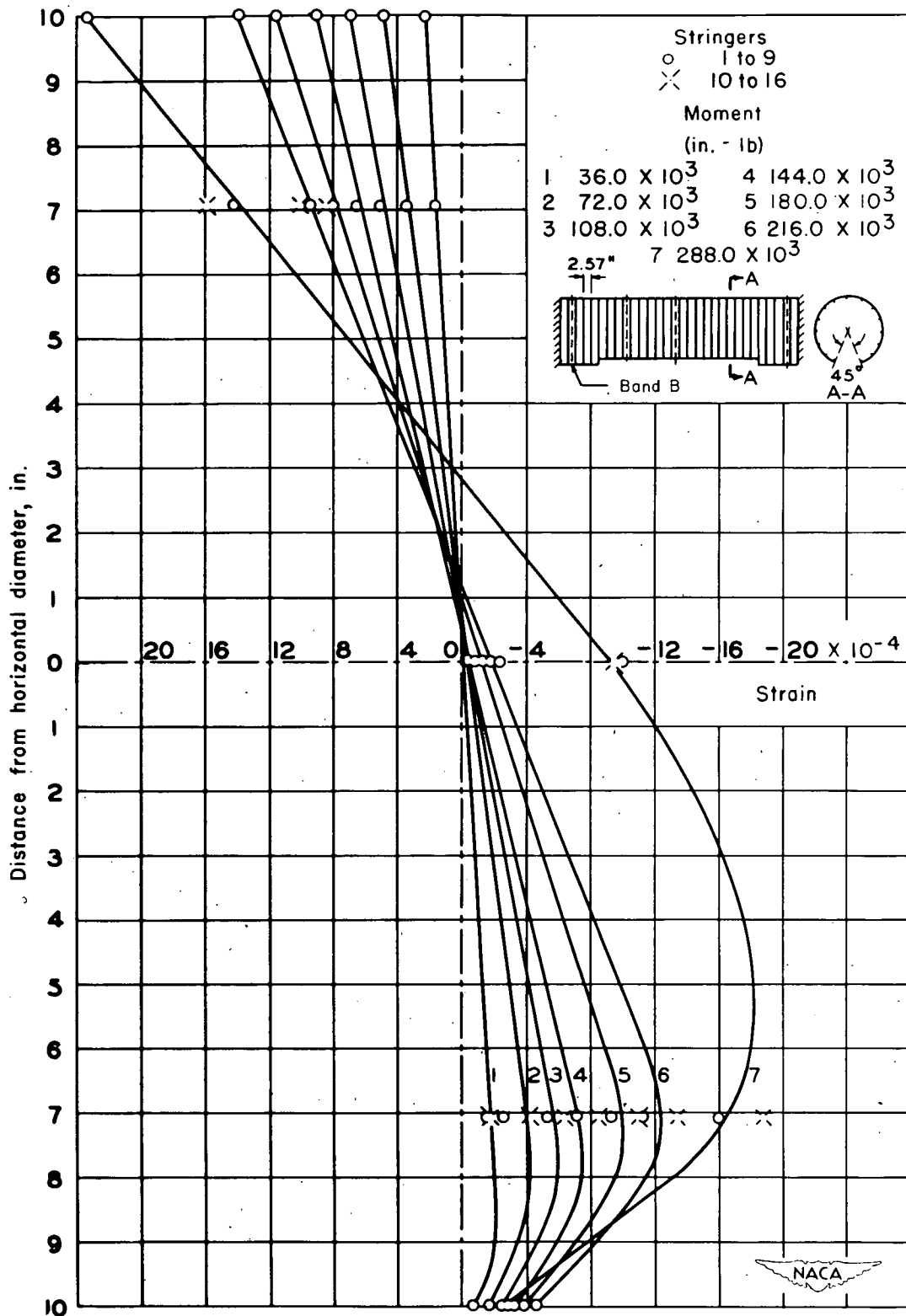


Figure 17.- Strain diagram of cylinder 77. Band B.

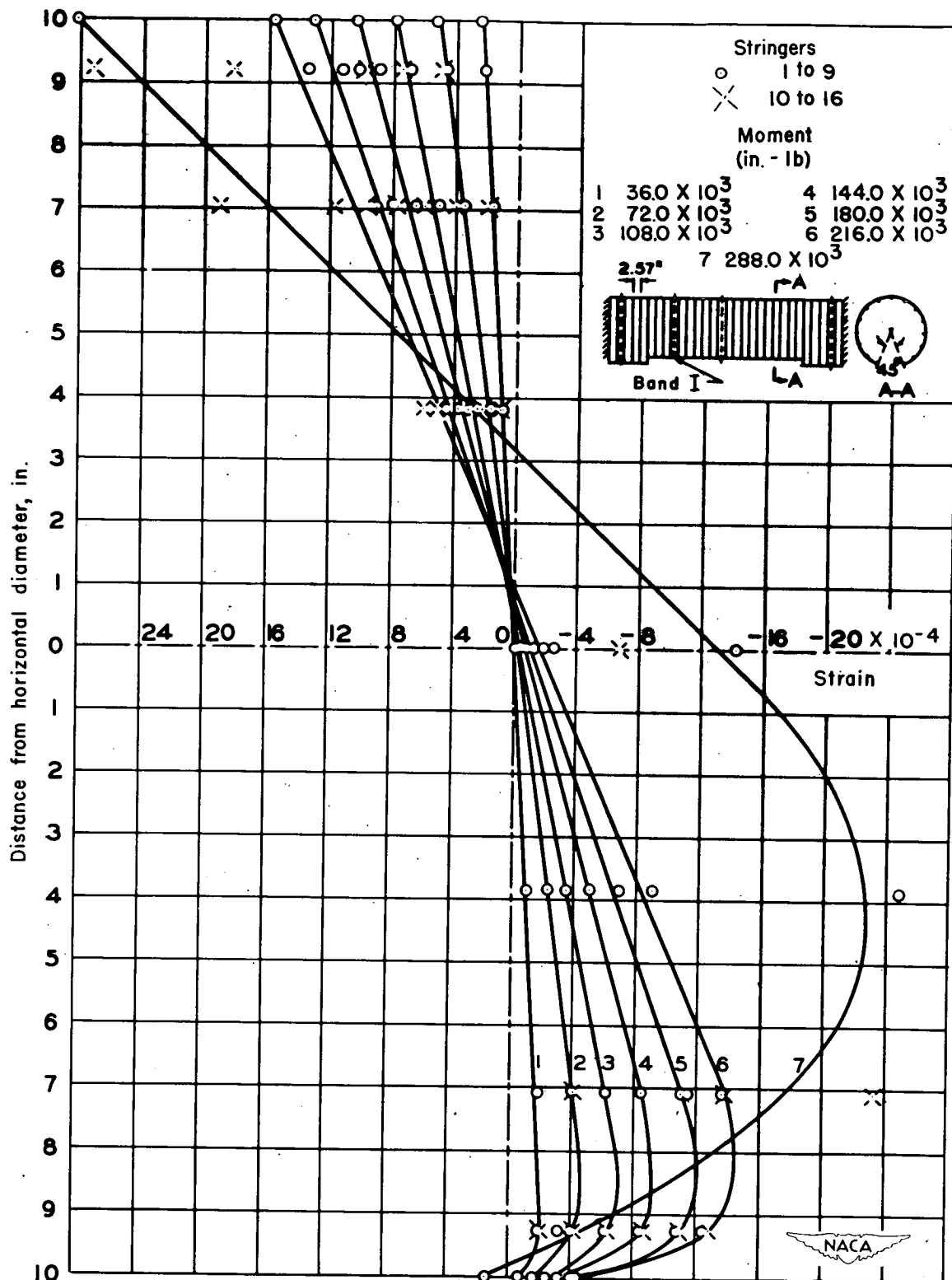


Figure 18.- Strain diagram of cylinder 77. Band I.

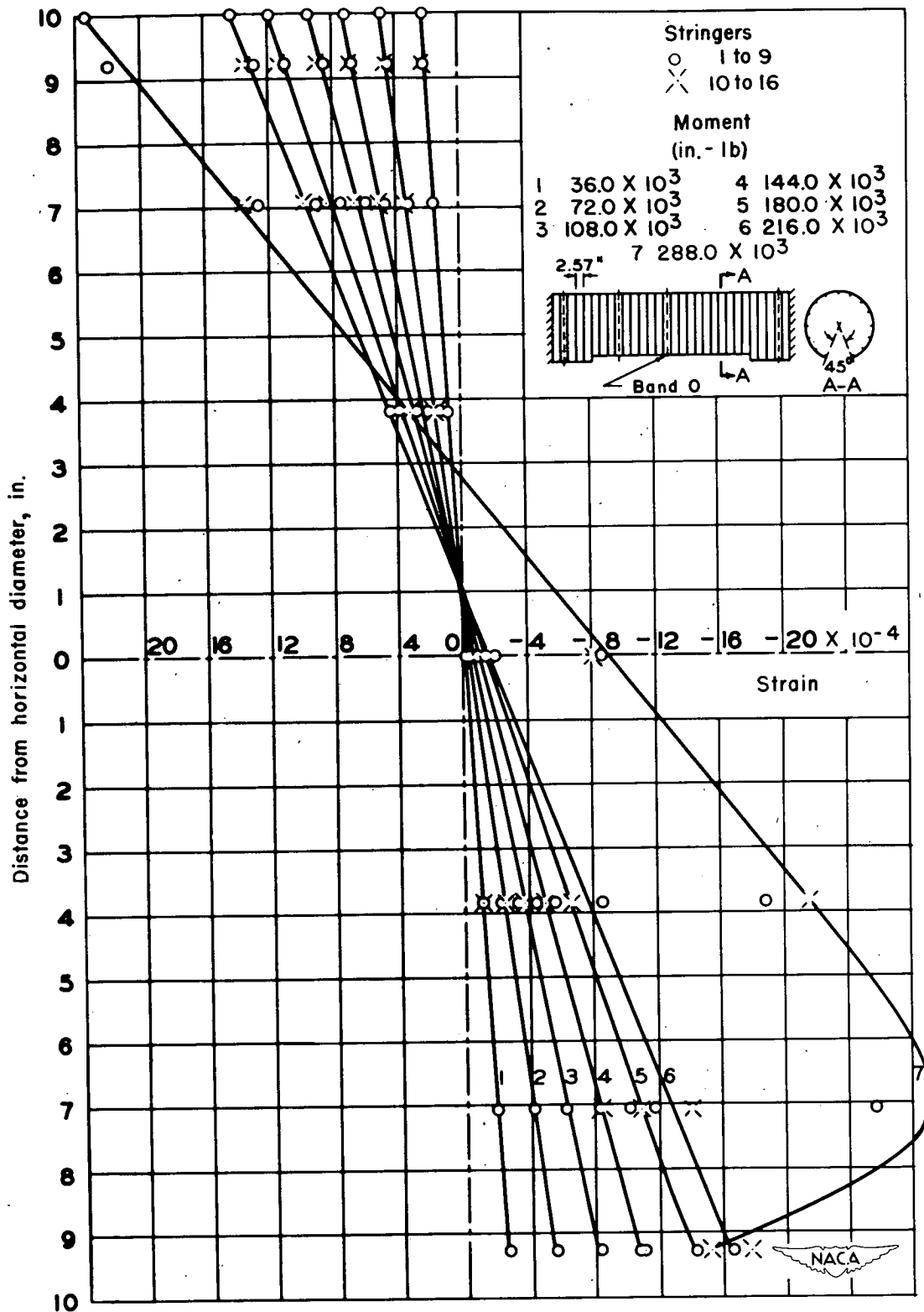


Figure 19.- Strain diagram of cylinder 77. Band O.

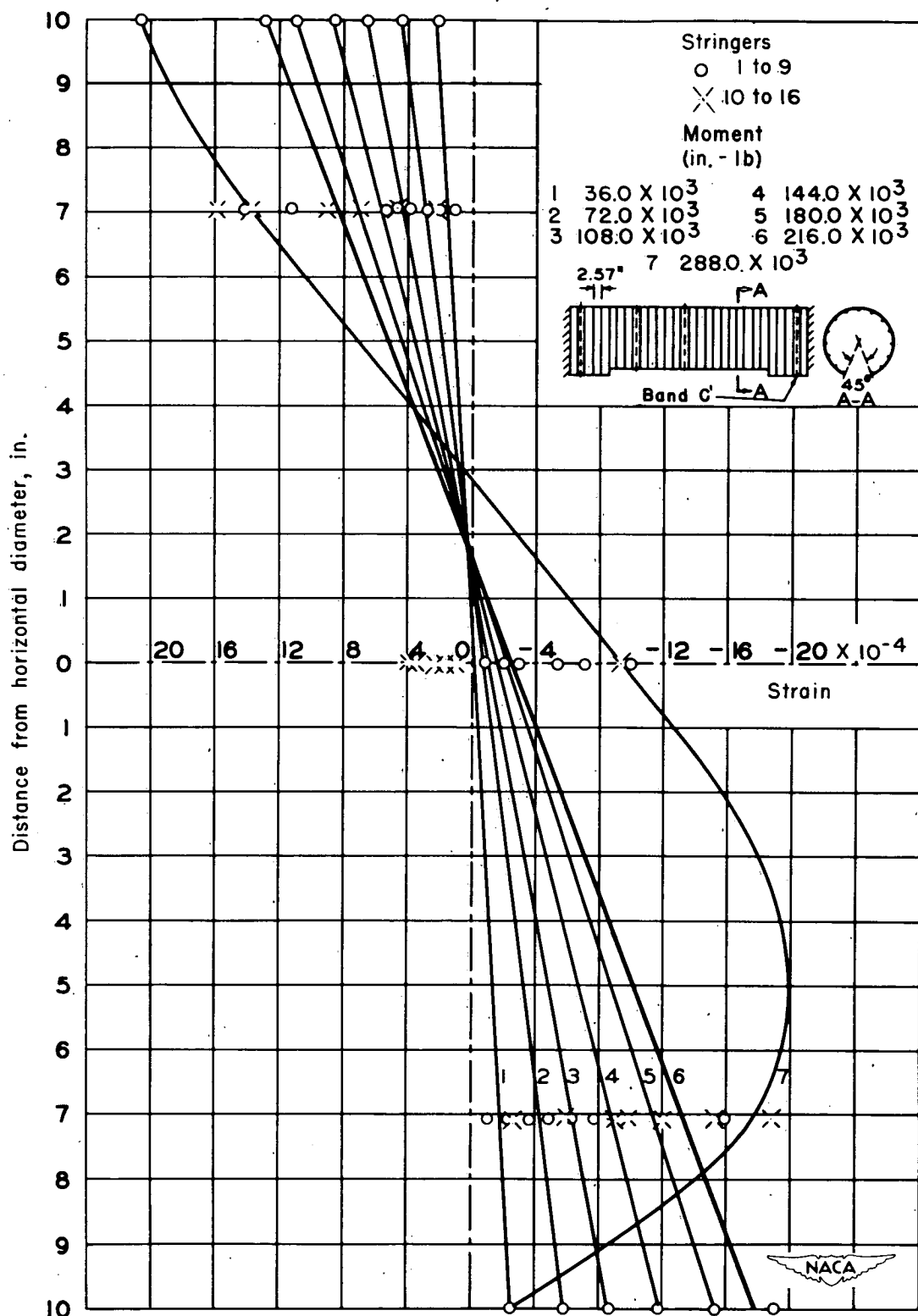


Figure 20.- Strain diagram of cylinder 77. Band C'.

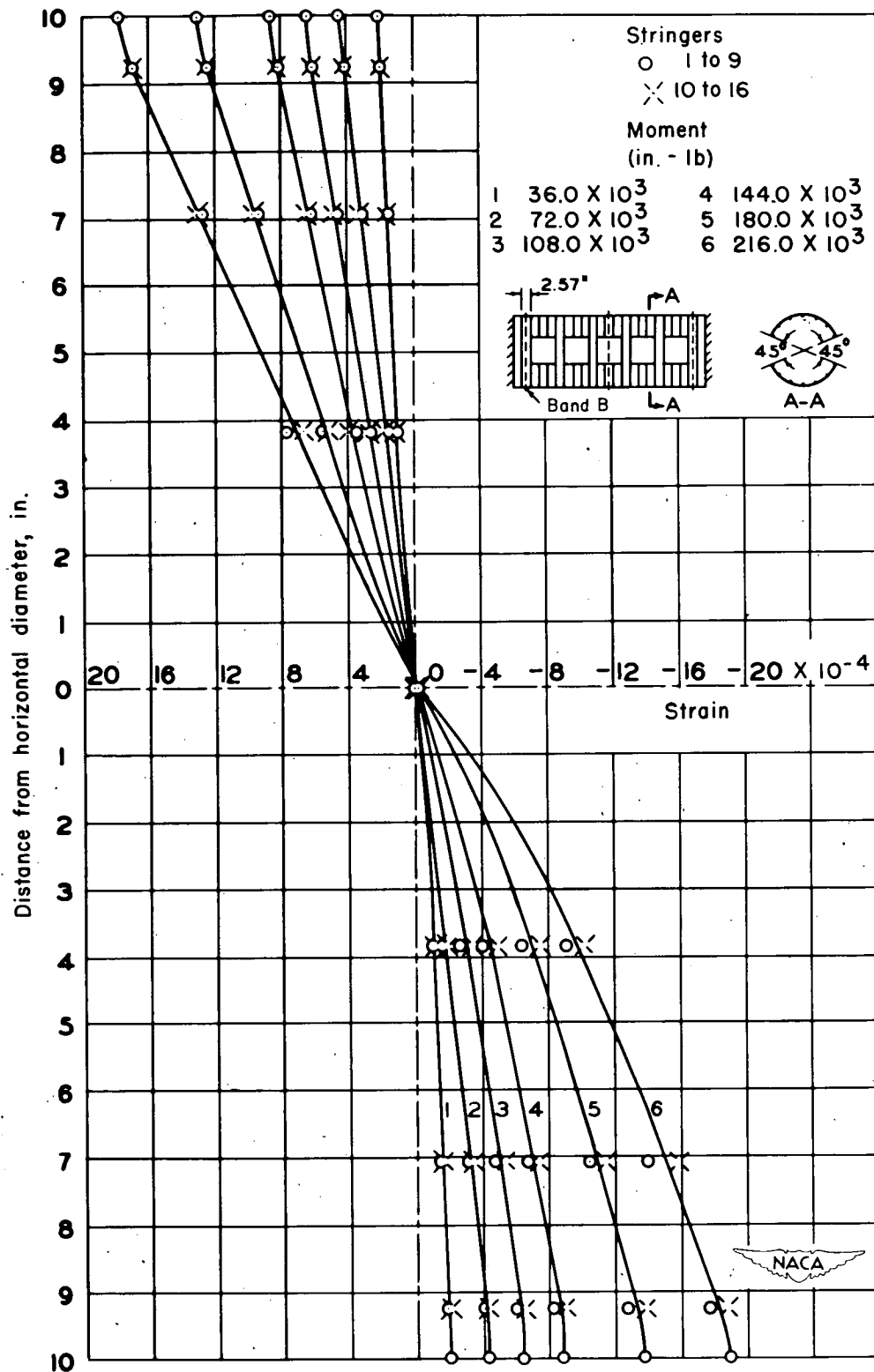


Figure 21.- Strain diagram of cylinder 78. Band B.

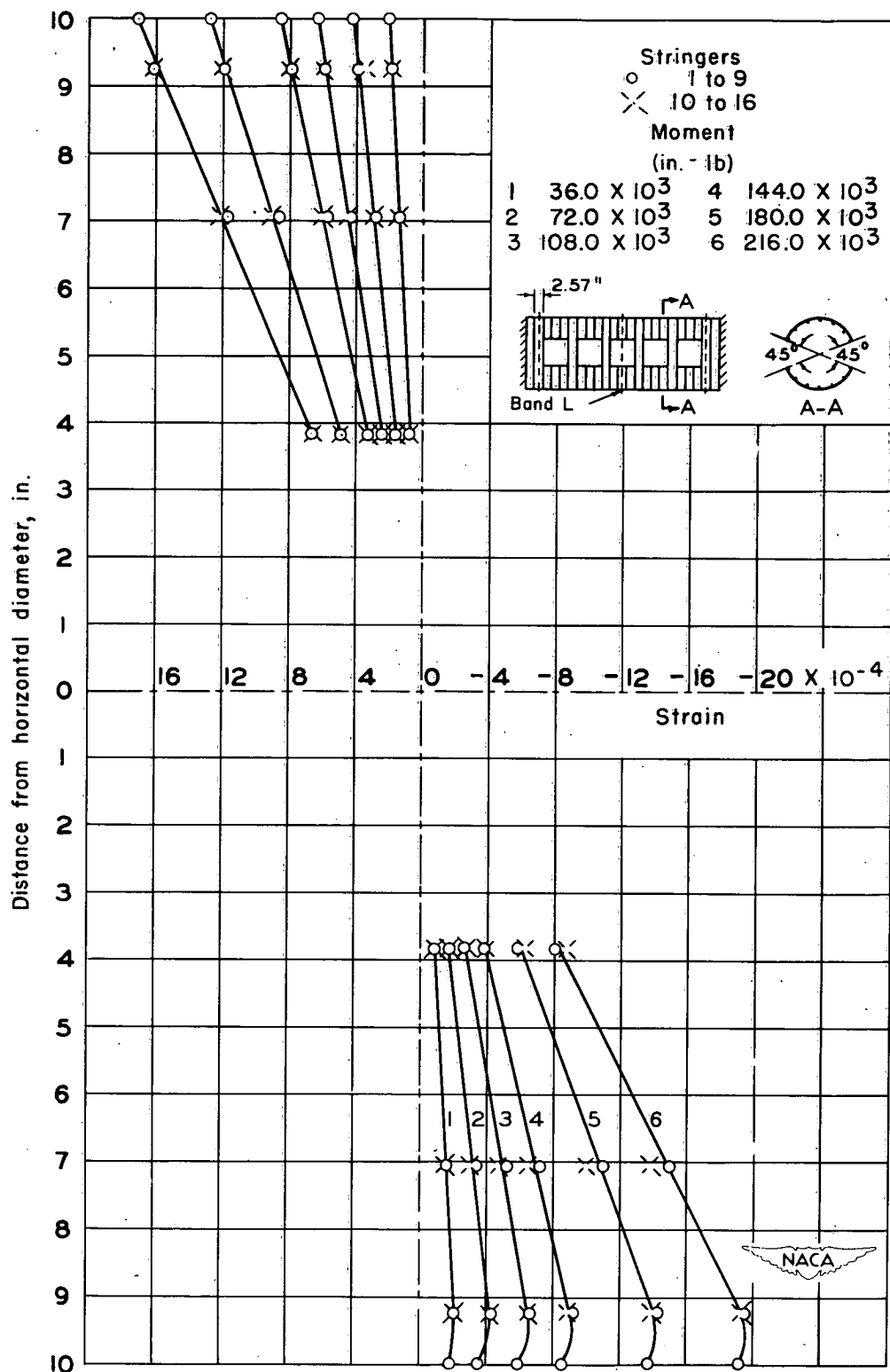


Figure 22.- Strain diagram of cylinder 78. Band L.

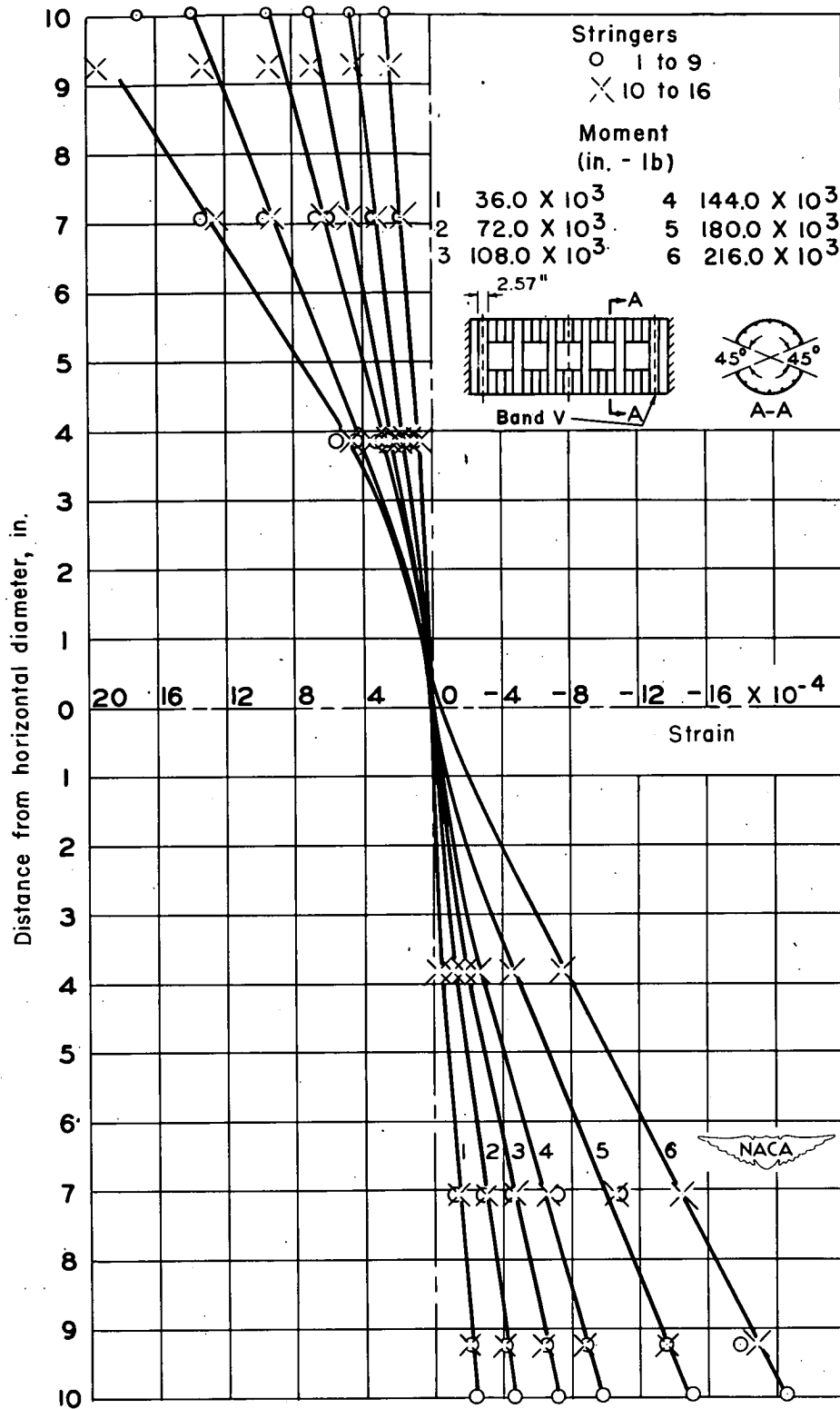


Figure 23.- Strain diagram of cylinder 78. Band V.

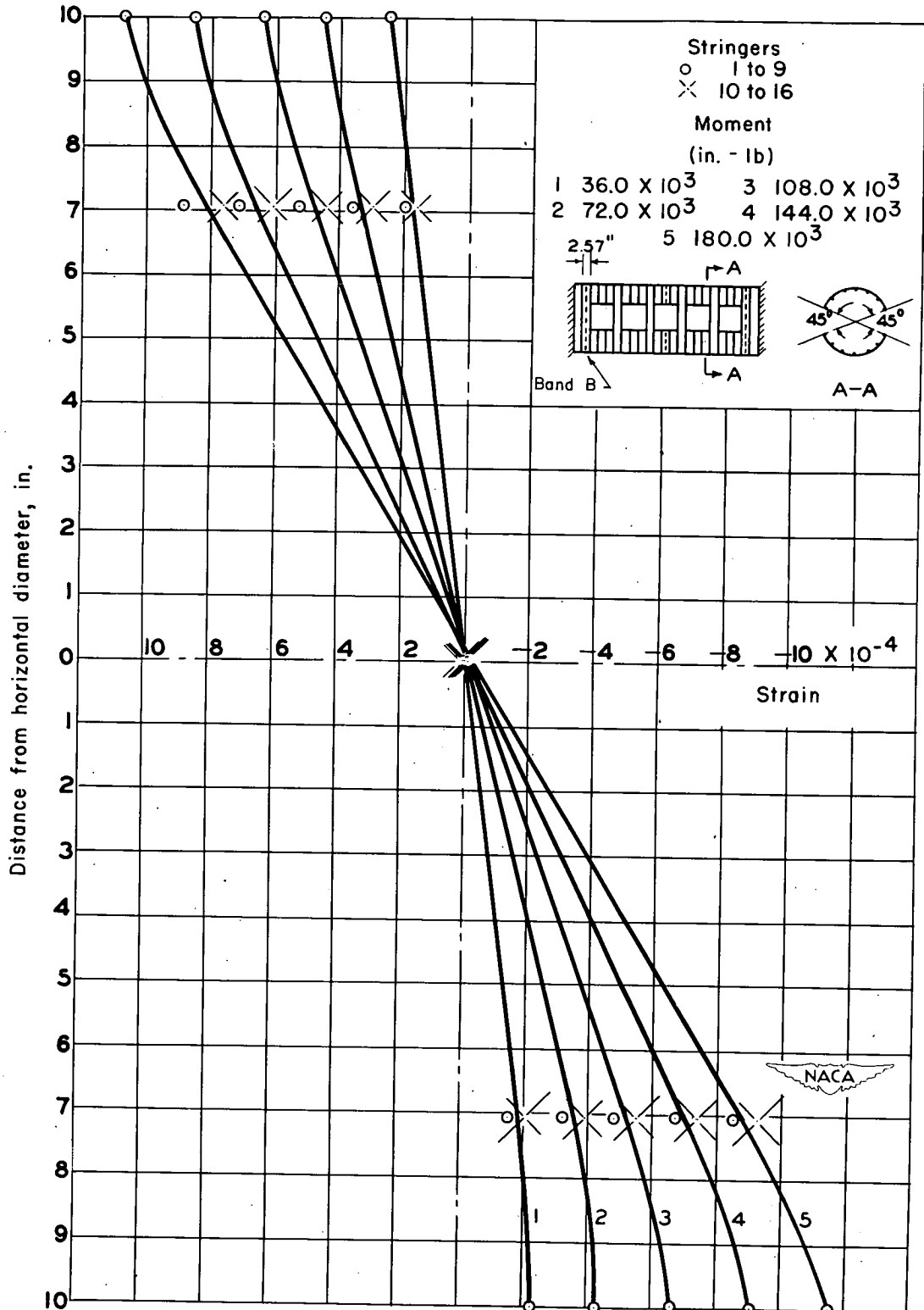


Figure 24.- Strain diagram of cylinder 79. Band B.

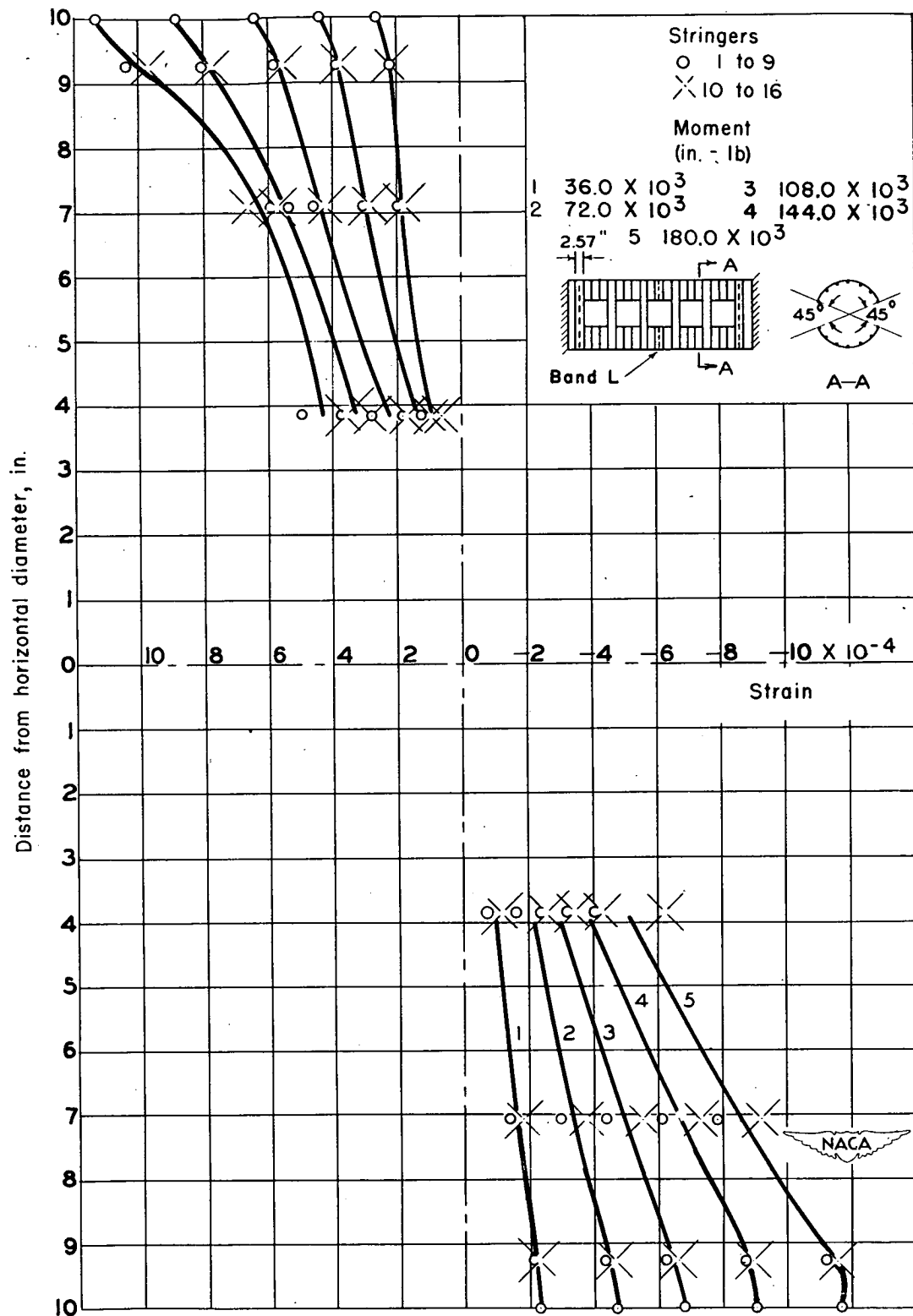


Figure 25.- Strain diagram of cylinder 79. Band L.

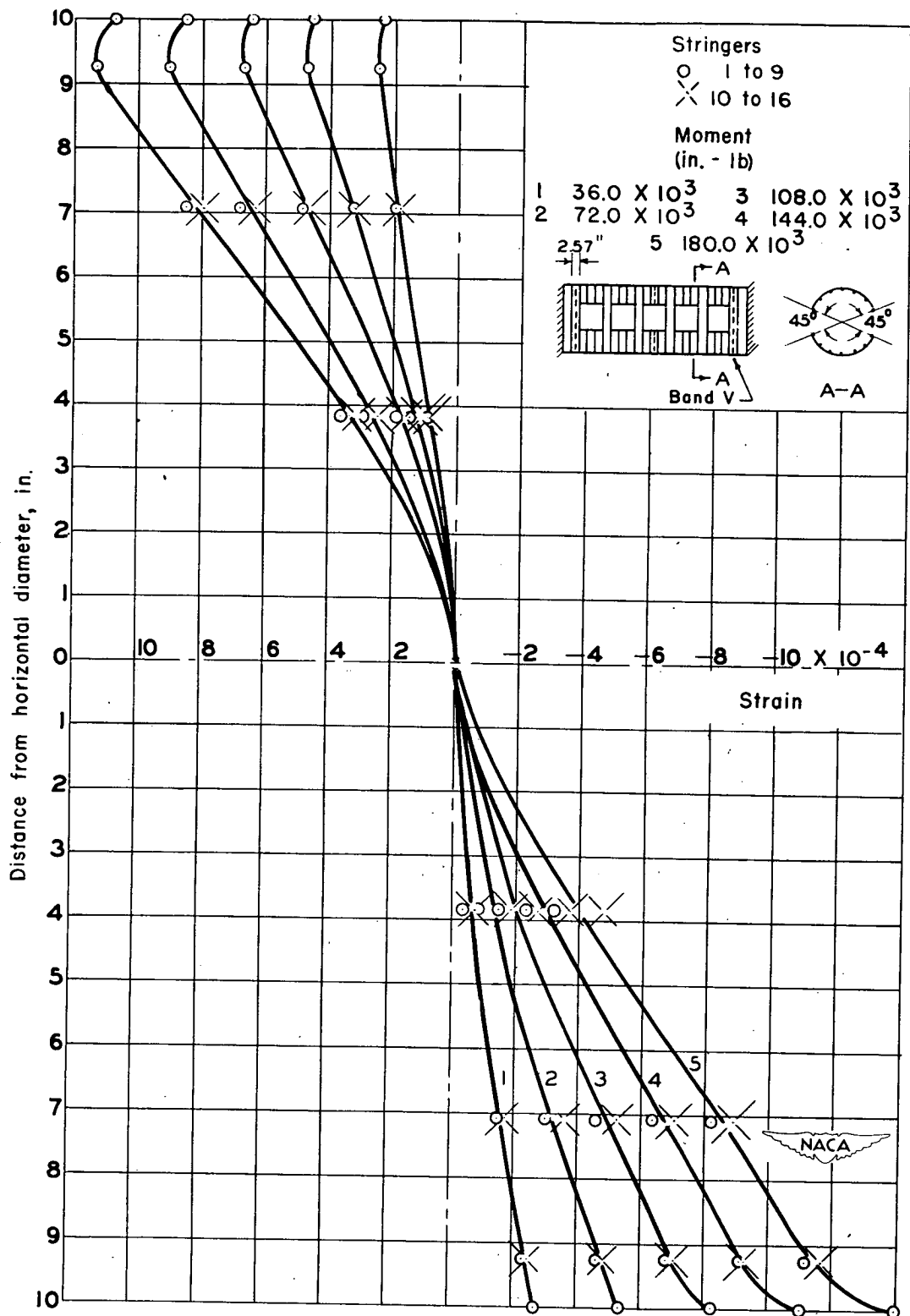


Figure 26.- Strain diagram of cylinder 79. Band V.

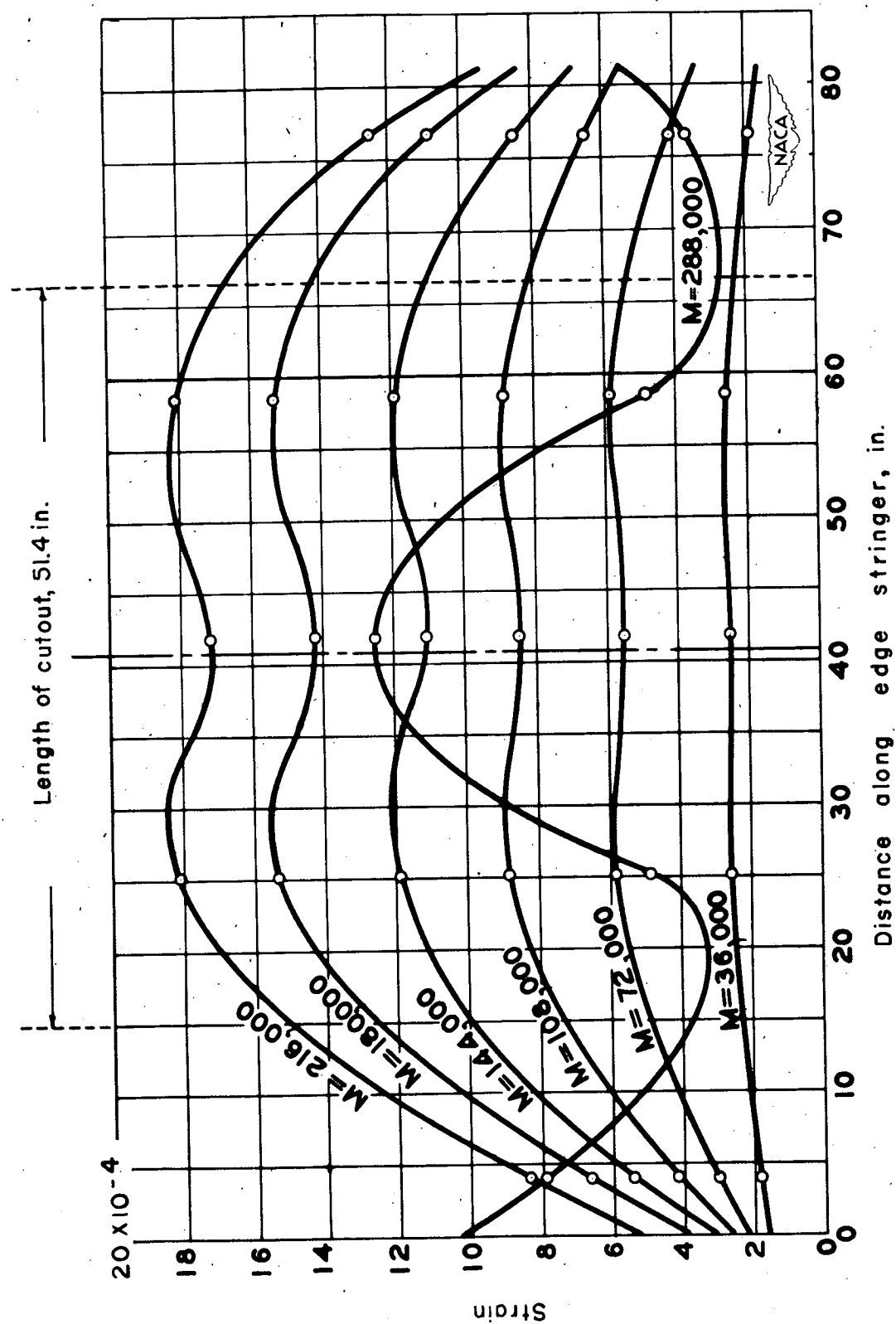


Figure 27.- Variation of strain along stringer at edge of cutout. Cylinder 77. M, moment, inch-pounds.

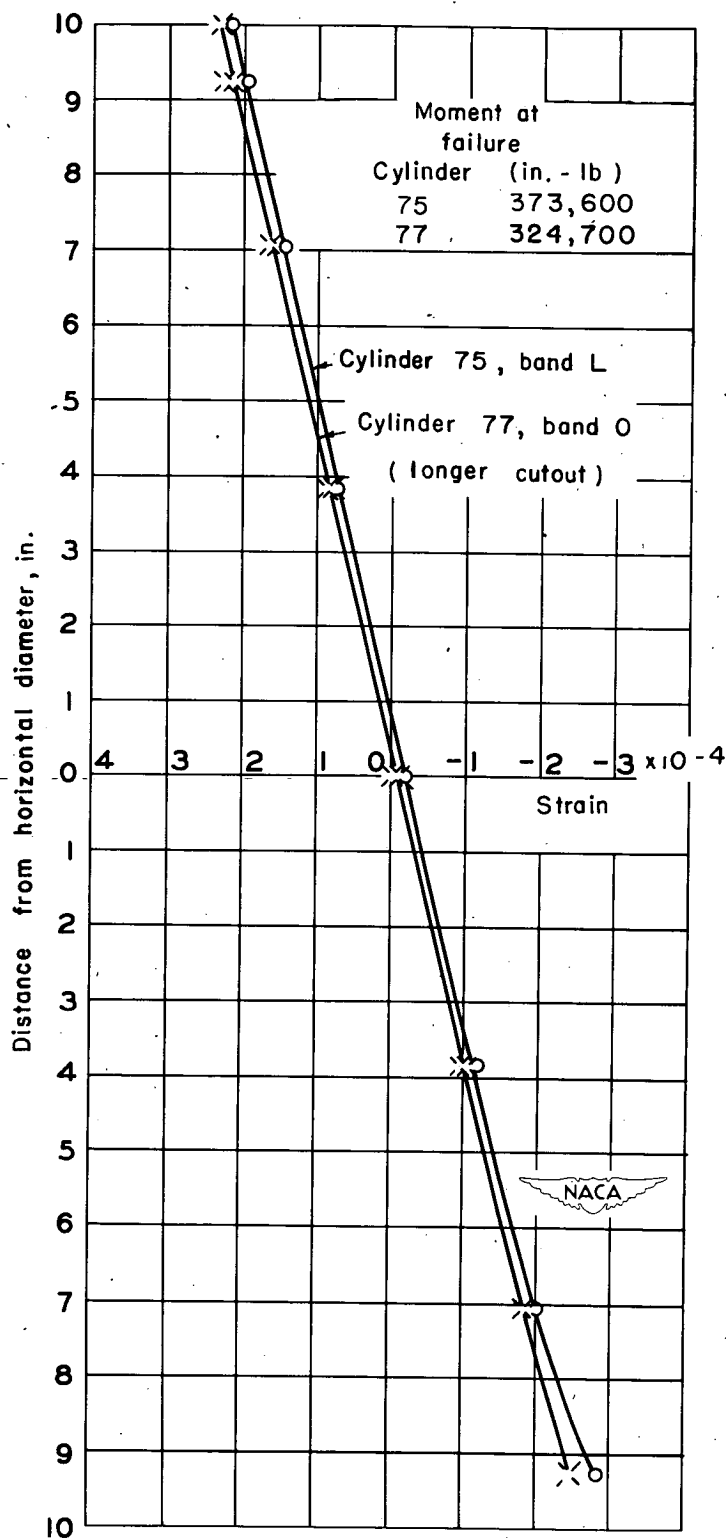


Figure 28.- Effect of length of cutout on strain distribution. Load, 500 pounds.

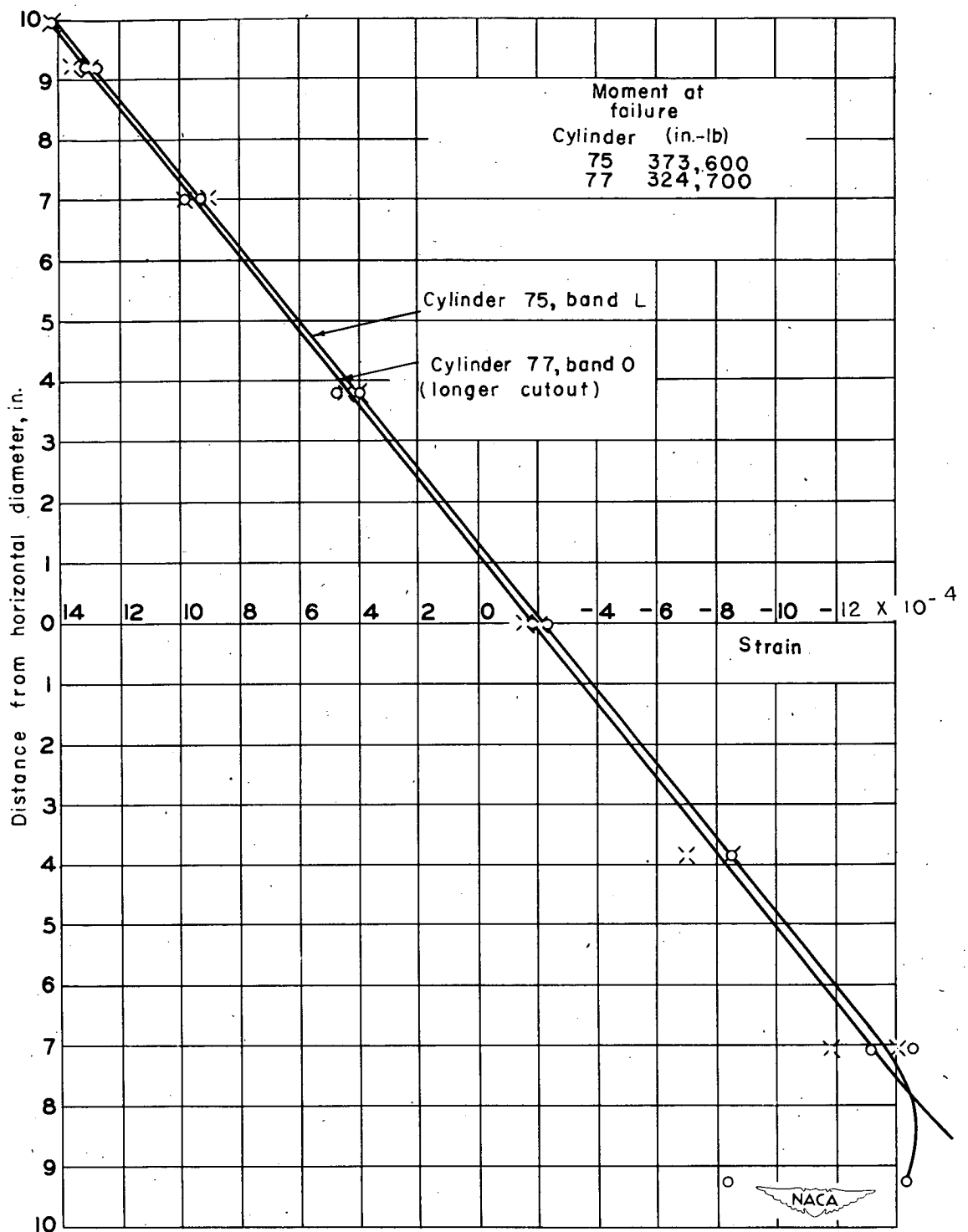


Figure 29.- Effect of length of cutout on strain distribution. Load, 3000 pounds.

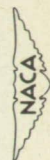


Figure 30.- Side view of cylinder 72 after buckling. Near side or stringer 8.

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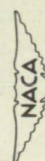
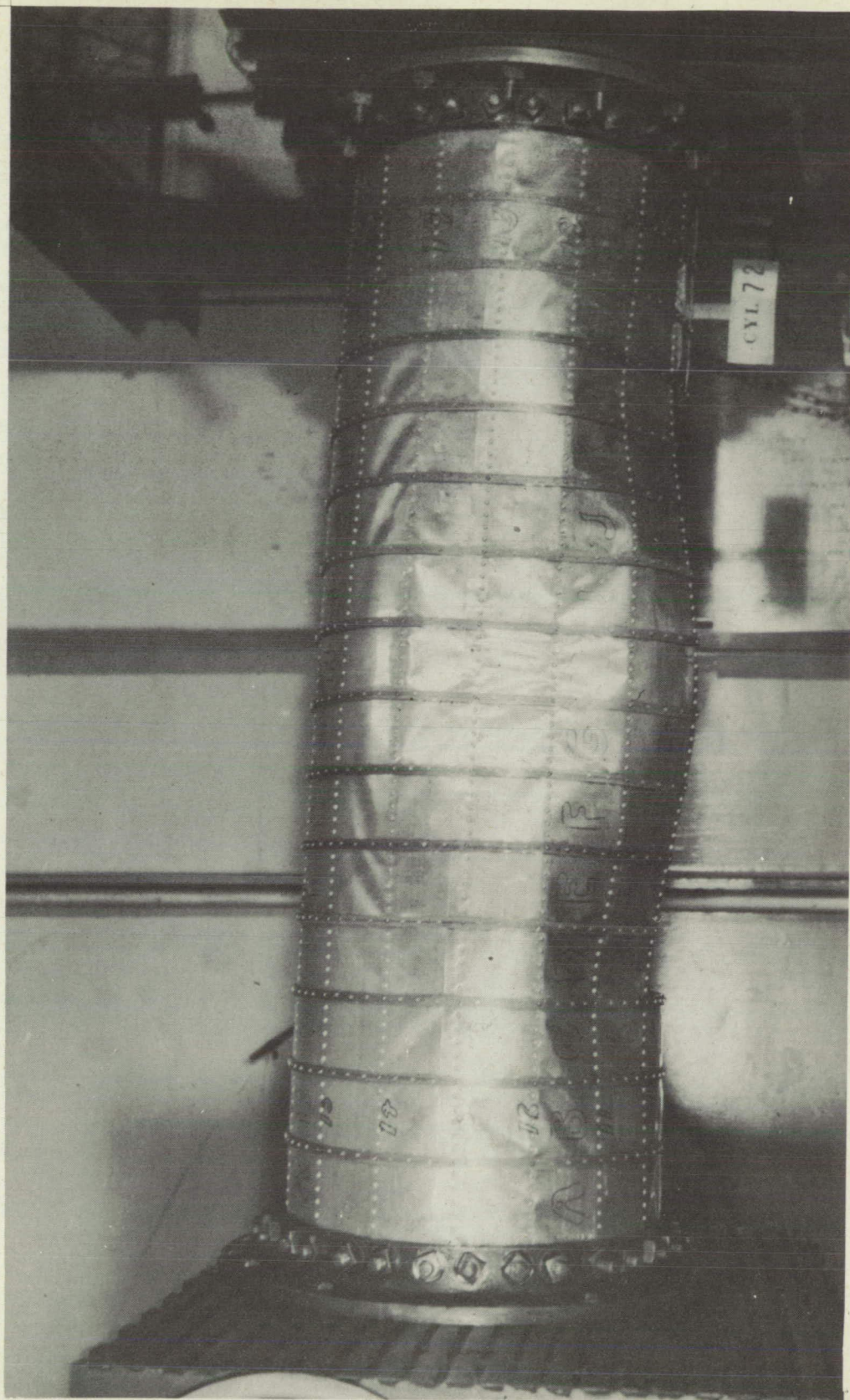


Figure 31.- Side view of cylinder 72 after buckling. Far side or stringer 11.

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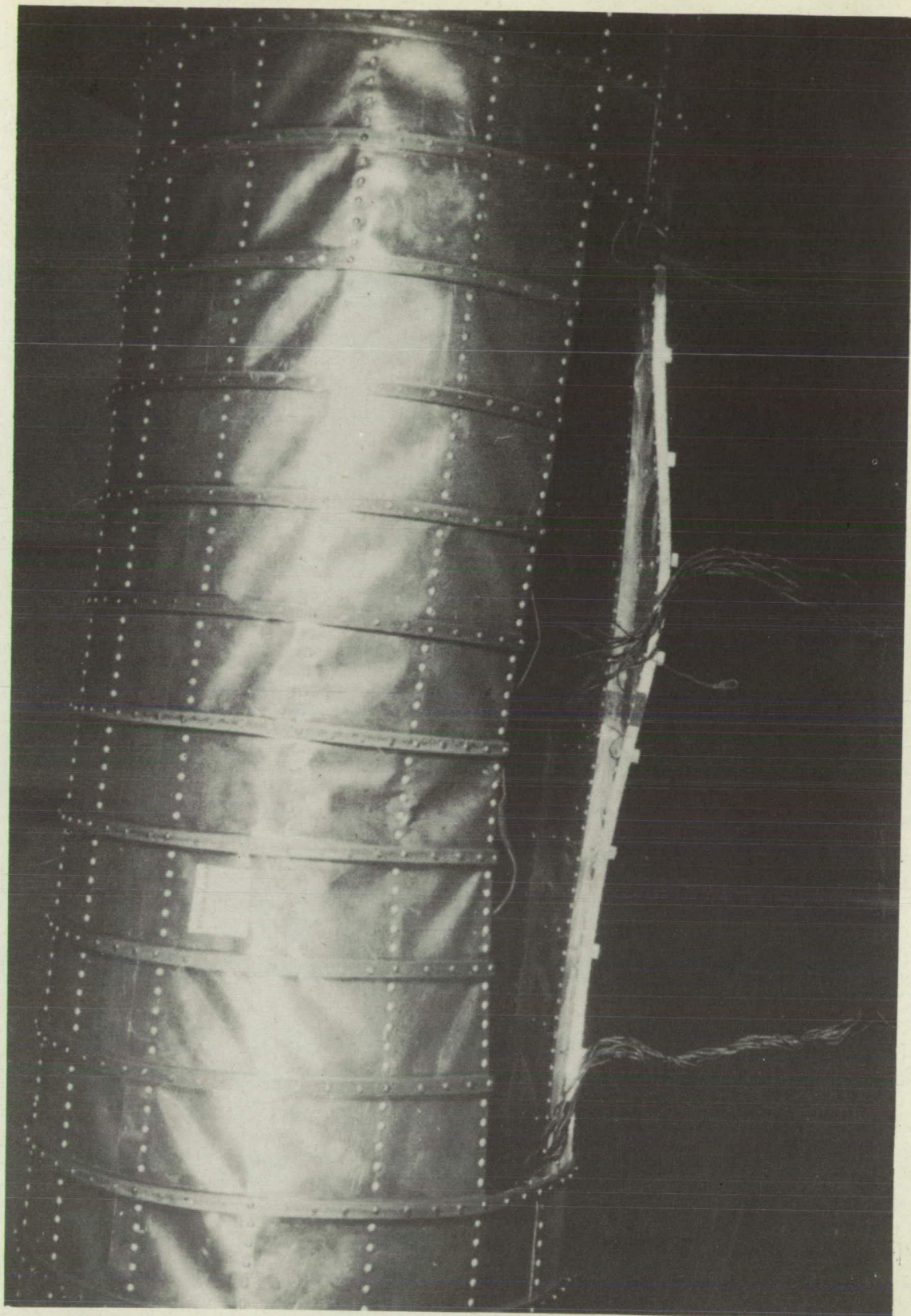


Figure 32.- Side view of cylinder 73 after buckling.

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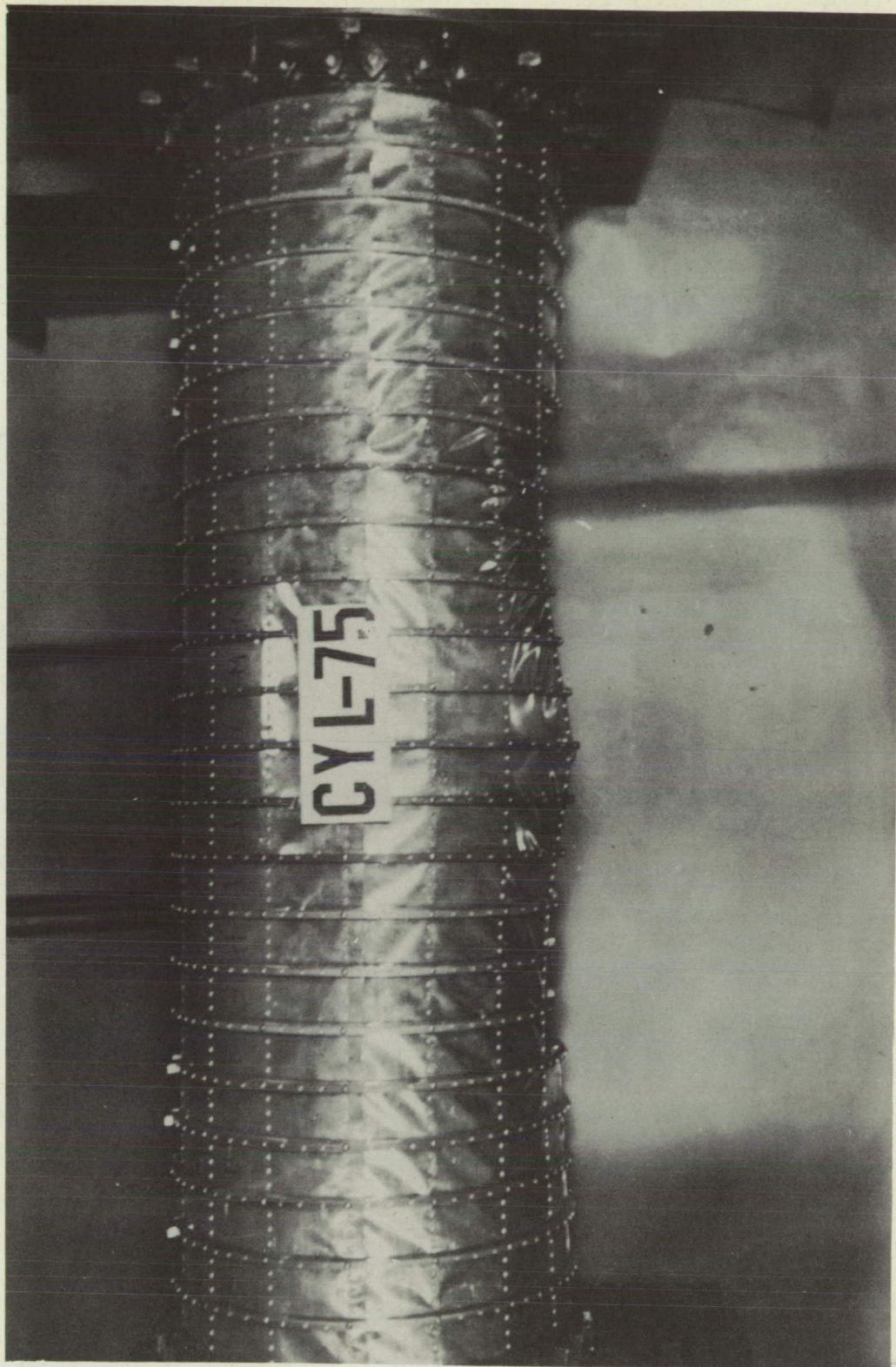


Figure 33.- Side view of cylinder 75 after buckling.

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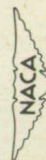


Figure 34.- Bottom view of cylinder 75 after buckling.

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Figure 35.- Side view of cylinder 76 after buckling.

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 Figure 36.- Side view of cylinder 77 after buckling.

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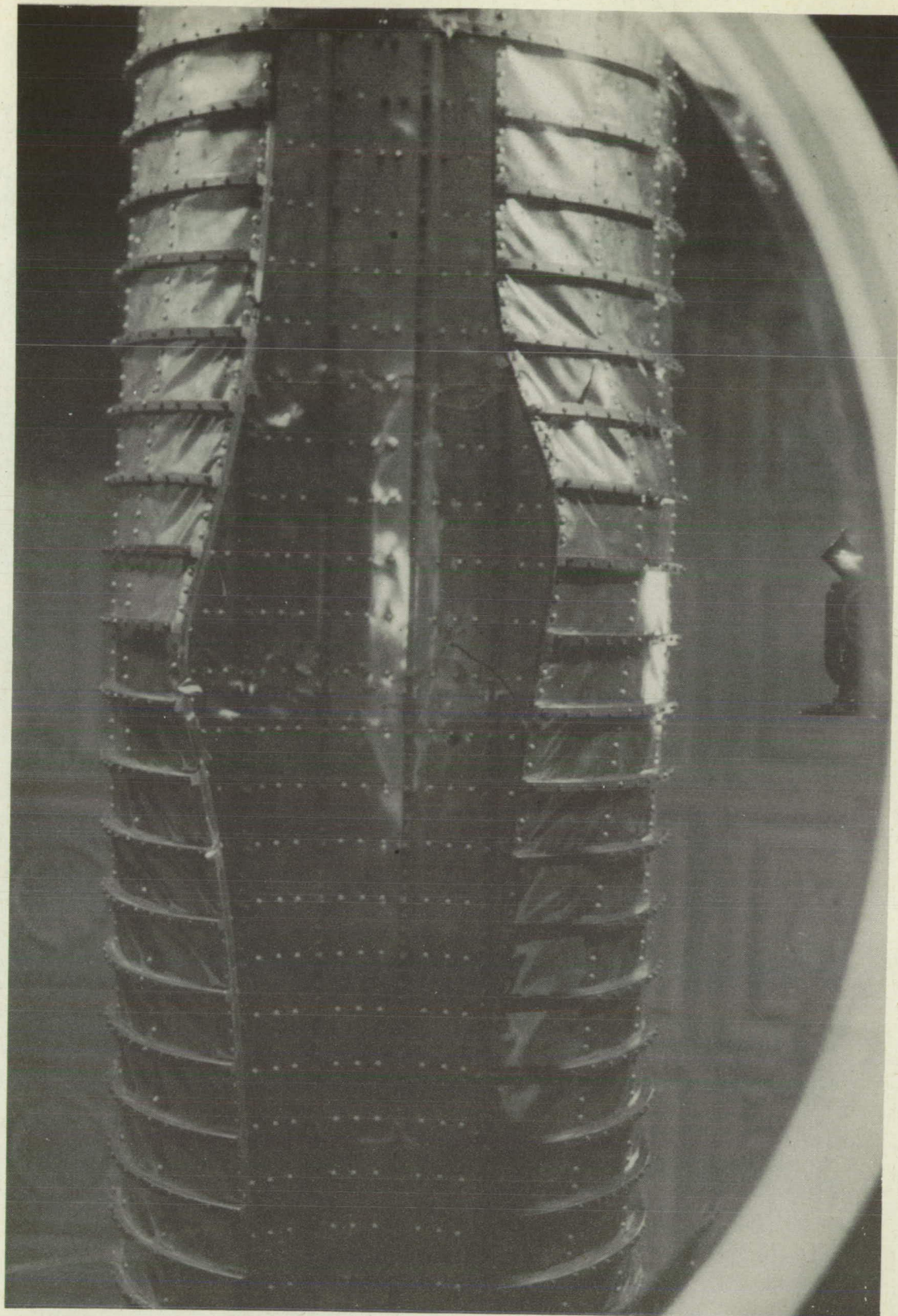
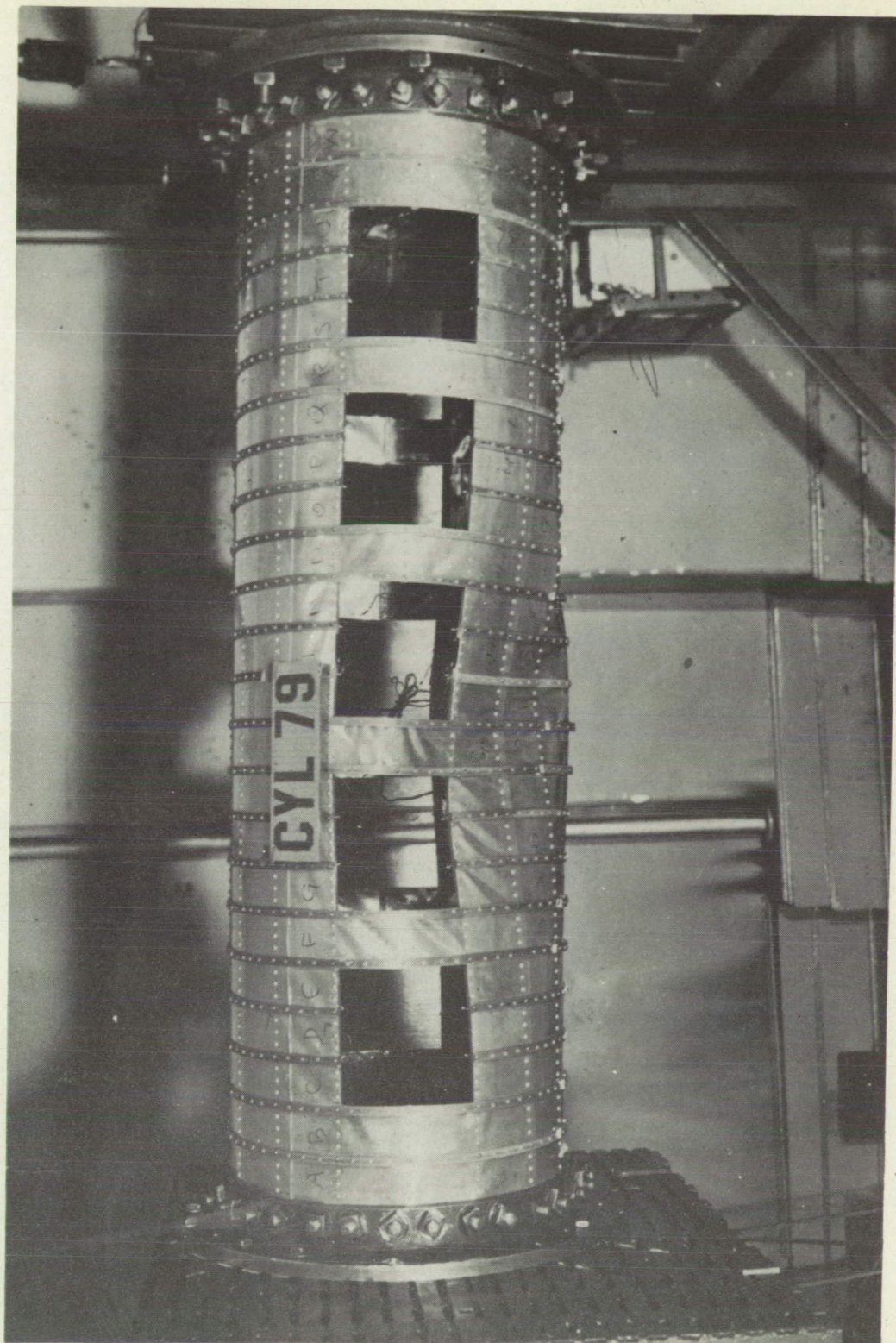


 Figure 37.- Bottom view of cylinder 77 after buckling.

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Figure 38.- Side view of cylinder 79 after buckling.